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ANTENNA AND PROPAGATION STUDIES FOR SPACECRAFT SYSTEMS

TASK E-53 I

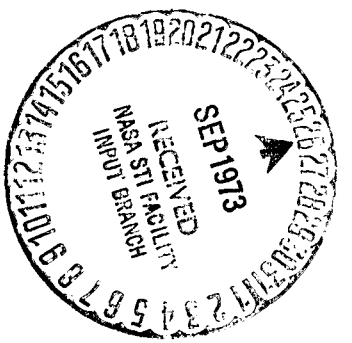
TECHNICAL REPORT

ADDENDUM TO PREFLIGHT SL-1/SL-3 SKYLAB VHF RANGING COVERAGE (EARLY AND LATE TPI)

NAS 9-12330

25 July 1973

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JOHNSON SPACE CENTER
HOUSTON, TEXAS



Prepared by
Electronic Systems Engineering Department

TRW
SYSTEMS GROUP

20029-H203-R0-01

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ADDENDUM TO PREFLIGHT SL-1/SL-3 VHF RANGING COVERAGE (EARLY AND LATE TPI)

1. INTRODUCTION AND SUMMARY

This addendum presents a preflight assessment of the expected Skylab VHF ranging coverage for the rendezvous portion of the SL-1/SL-3 mission, assuming a 28 July 1973 launch date, for the alternative trajectory cases characterized by either an early TPI or a late TPI. In this assessment "early TPI" and "late TPI" are used to indicate a TPI maneuver occurring 10 minutes prior to or after the nominally scheduled TPI maneuver, respectively. Again, as in the nominal case, the Saturn Workshop (SWS) maintains a solar inertial (SI) attitude throughout rendezvous for both trajectory cases.

The results summarized in this report concern VHF ranging function performance during that period most likely to be affected by off-nominal TPI conditions, i.e., NSR (5:56 g.e.t.) to station keeping. Consequently, it should be noted that tracking periods prior to NSR that have been previously identified for the nominal case, although excluded from the present discussion, do exist.

Curves are presented in Appendix A of this report which show the variation in received power levels on both spacecraft-to-spacecraft links from about 100 n.mi. range to CSM and SWS station keeping. Appropriate threshold levels are shown on these received power curves to indicate zero circuit margins for the ranging function.

The overall performance of the VHF ranging links is summarized in the bar charts presented in Section 2. These bar charts are based on the received power curves, where the bars represent positive circuit margins, and the gaps represent negative margins. Positive circuit margin bars

begin only when the received power is greater than or equal to -104 dBm and do not drop out until the received power falls below -107 dBm. The VHF ranging duplex link summary bar chart presents expected acquisition, availability, and loss of the VHF ranging function, since the VHF system will be operating in the duplex mode where adequate margins are required both on the link from the CSM to the SWS and on the return link.

Based on an examination of the variation in received power on the two VHF links (using either the right CSM VHF antenna or the left CSM VHF antenna) as a function of mission time, the following conclusions and recommendations are made:

1) The SWS solar inertial attitude causes the expected VHF ranging coverage to be very sparse. Ranging coverage is available roughly once each orbital revolution, during that relatively short interval when the SWS happens to be favorably oriented toward the CSM.

2) All trajectory cases show best performance with the CSM right antenna, which should be selected throughout the entire rendezvous sequence. This link shows the least amount of multipath interference and should allow the earliest possible acquisition of the ranging function during each revolution. For the final, or "docking" revolution, a nominal TPI maneuver would result in VHF ranging capability at a greater range (24 n.mi.) than would an early TPI (16 n.mi.) and, similarly, a late TPI burn would permit VHF ranging at an even greater distance (40 n.mi.) than would the nominal TPI. As a function of mission time the VHF ranging capability will be available no later than 7:09 g.e.t., 7:10 g.e.t., and 7:07 g.e.t. for early (7:02 g.e.t.), nominal (7:12 g.e.t.) and late TPI (7:22 g.e.t.), respectively.

3) Using a ranging acquisition threshold of -104 dBm, a tracking dropout threshold of -107 dBm, and the minimum received power data (direct signal minus multipath signal), the minimum availability of the ranging function (using CSM-RT/SWS link only) is outlined below:

TABLE I

	ACQUISITION (CSM RT/SWS only)		DROPOUT (CSM RT/SWS only)	
	TIME (hr:min.,g.e.t.)	RANGE (n.mi.)	TIME (hr:min,g.e.t.)	RANGE (n.mi.)
Early TPI (7:02)	5:57	88	5:58	86
	7:09	16	Station Keeping	
Late TPI (7:22)	7:07	38	Station Keeping	

The coverage assessment in this report is based on operational attitude trajectory information, as supplied by the SL-1/SL-3 rendezvous attitude tapes for a 28 July 1973 SL-3 launch (NASA/JSC tapes A14260 and A00851, early TPI and late TPI, respectively) [1]. This coverage assessment is also based on antenna pattern data supplied by NASA/JSC, as documented in [2]. The system parameter values used in this assessment can be found in Appendix B of [2].

2. TECHNICAL DISCUSSION

2.1 OBJECTIVES

The objectives of this addendum to the Preflight SL-1/SL-3 Skylab VHF Ranging Coverage Study are 1) to determine how slippage of the TPI maneuver affects the availability of the VHF ranging capability in the vicinity of TPI and 2) to select the optimum antenna combinations to be used at specific times throughout the rendezvous sequence.

2.2 ASSUMPTIONS

The coverage study in this report is based on the assumptions that

1) The NASA operational rendezvous trajectory tapes A14260 and A00851 are accurate representations of the rendezvous portion of the SL-1/SL-3 Skylab mission [1].

2) The CSM and SWS antenna patterns stored in the HV014E computer program accurately represent the true antenna patterns. (See the Preliminary Skylab VHF Ranging Coverage Report [2] for the assumed radiation pattern contour plots.)

3) The system parameter values given in Appendix B of [2] accurately represent the actual values.

4) VHF ranging signals will be transmitted from the CSM on 259.7 MHz and received by the CSM on 296.8 MHz.

5) No communication degradation occurs due to engine plume effects while engines are thrusting.

2.3 METHOD OF ASSESSMENT

The Skylab VHF ranging coverage study makes use of the TRW-developed VHF Computer Analysis Program, HV014E, run on the NASA UNIVAC 1108 system in conjunction with a TRW-modified, Grumman-developed [3] Circuit Margin Performance Analysis Program (CMPAP), which has been incorporated as an integral part of HV014E [4].

The computer output consists of printouts and plots (via the TRWPLT general plotting program) of the range between the CSM and SWS as a function of mission time, and the corresponding CSM and SWS look angles, total received power, CSM and SWS antenna gains, polarization losses, and gain products at each time point. Only the range, look angle, antenna gain, and total received power plots have been included in this report, where the plots showing total received power in dBm also show threshold levels corresponding to zero dB circuit margins for the VHF ranging function; the threshold values and other system parameters are summarized in Appendix B of Reference [2].

The maximum and minimum received power plots presented in Appendix A indicate the amount of signal fluctuation to be expected from multipath effects. The maximum curves give the total received power for the condition where the direct and multipath signals add in-phase. The minimum curves give the total received power when the direct and multipath signals are out-of-phase. Since the actual phase difference between the direct and multipath signals varies rapidly as a function of time, the amplitude of the net received signal can be expected to fluctuate between the two extremes given by the maximum and minimum received power curves.

2.4 DETAILED EVALUATION OF SL-3

The VHF Ranging function will ba available only when the minimum received power on each of both the 296.8 MHz link and the 257.7 MHz link is above the ranging threshold. Using a ranging system acquisition threshold of -104 dBm and a tracking dropout threshold of -107 dBm, worst case tracking periods (minimum received power, i.e., maximum multipath interference) have been identified for the early and late TPI trajectory cases.

The bar charts presented in Figures 1 - 6 summarize the information available in the total received power plots. Simplex charts (Figures 1, 2, 4, and 5) represent one-way transmission-reception links. Each of the eight bars on the four charts corresponds to one of the total received

power plots. Each bar begins when the total received power reaches the acquisition threshold of -104 dBm. Gaps in the bars begin at those times for which the total received power has dropped below the tracking threshold of -107 dBm and end only when the acquisition threshold of -104 dBm has been achieved again.

The duplex bar charts (Figures 3 and 6) represent two-way links and are derived from the appropriate simplex charts. A gap in a duplex bar indicates that there is a gap in either of the two simplex bars from which the duplex bar was constructed. As a result, the presence of duplex bars represents those times for which the ranging function is available with the CSM transmitting on 259.7 MHz and receiving on 296.8 MHz.

2.4.1 SL-3 Early TPI (7:02 g.e.t.) Results

Based on the CSM right antenna to SWS helix antenna link, which provides the best overall performance margins, one tracking period has been identified.* This tracking period should begin about 7:09 g.e.t. (about 16 n.mi.) and continue without subsequent dropouts until the ranging system is turned off at CSM and SWS station keeping.

2.4.2 SL-3 Late TPI (7:22 g.e.t.) Results

The CSM-RT/SWS link provides the best overall performance margins in the event of a late TPI maneuver. Based on worst case received power plots only one tracking period is anticipated: from 7:07 g.e.t. (about 38 n.mi. range) until CSM and SWS station keeping.

---

* Two earlier tracking periods (from about 4:10 to 4:22 g.e.t. and from 5:35 to 5:56 g.e.t.) identified in the SL-1/SL-3 Skylab VHF Ranging Coverage (Nominal TPI) report [5] should still be available for both the early and late TPI trajectory cases. The second tracking period, which extends a few minutes past NSR, is partially evidenced on the bar charts.

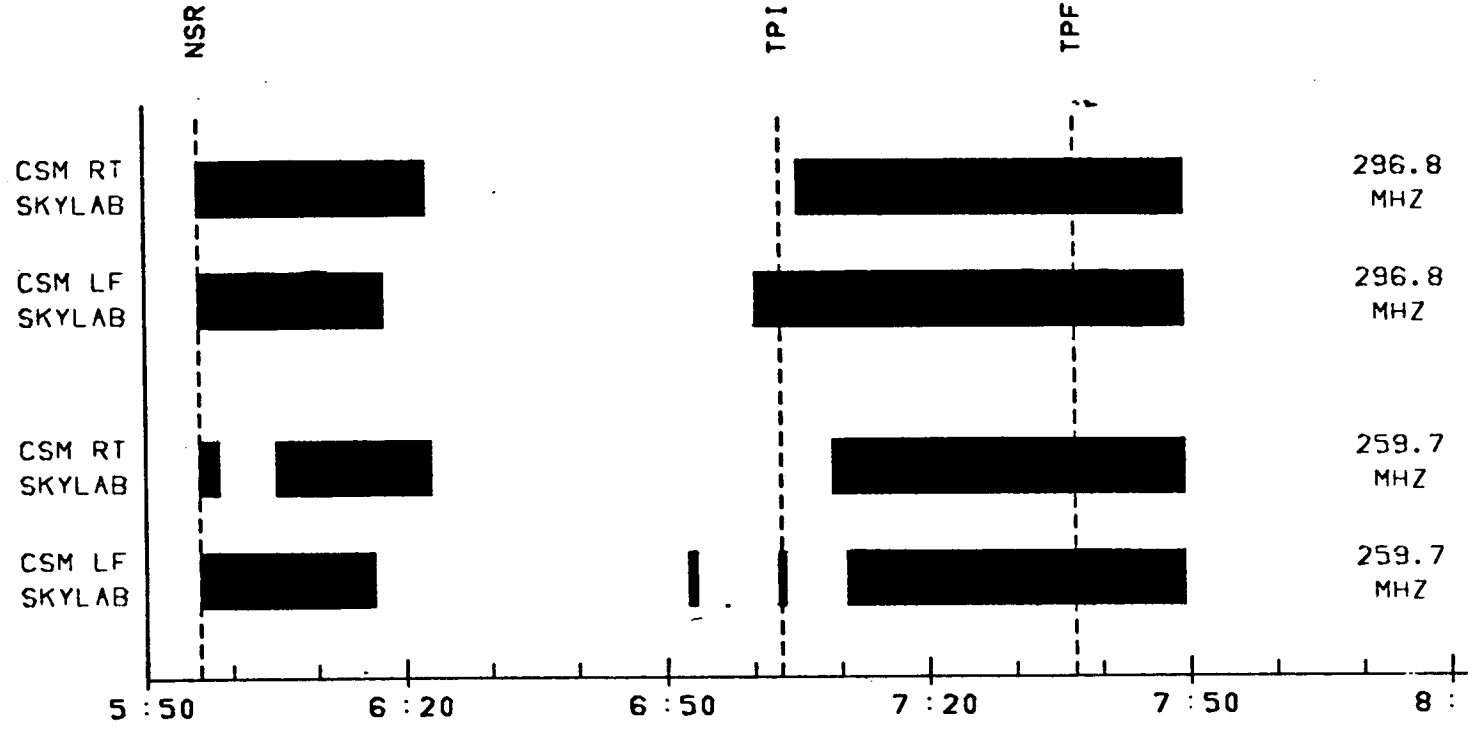

Figure 1. VHF Simplex Link Summary - Maximum Signal (Early TPI)

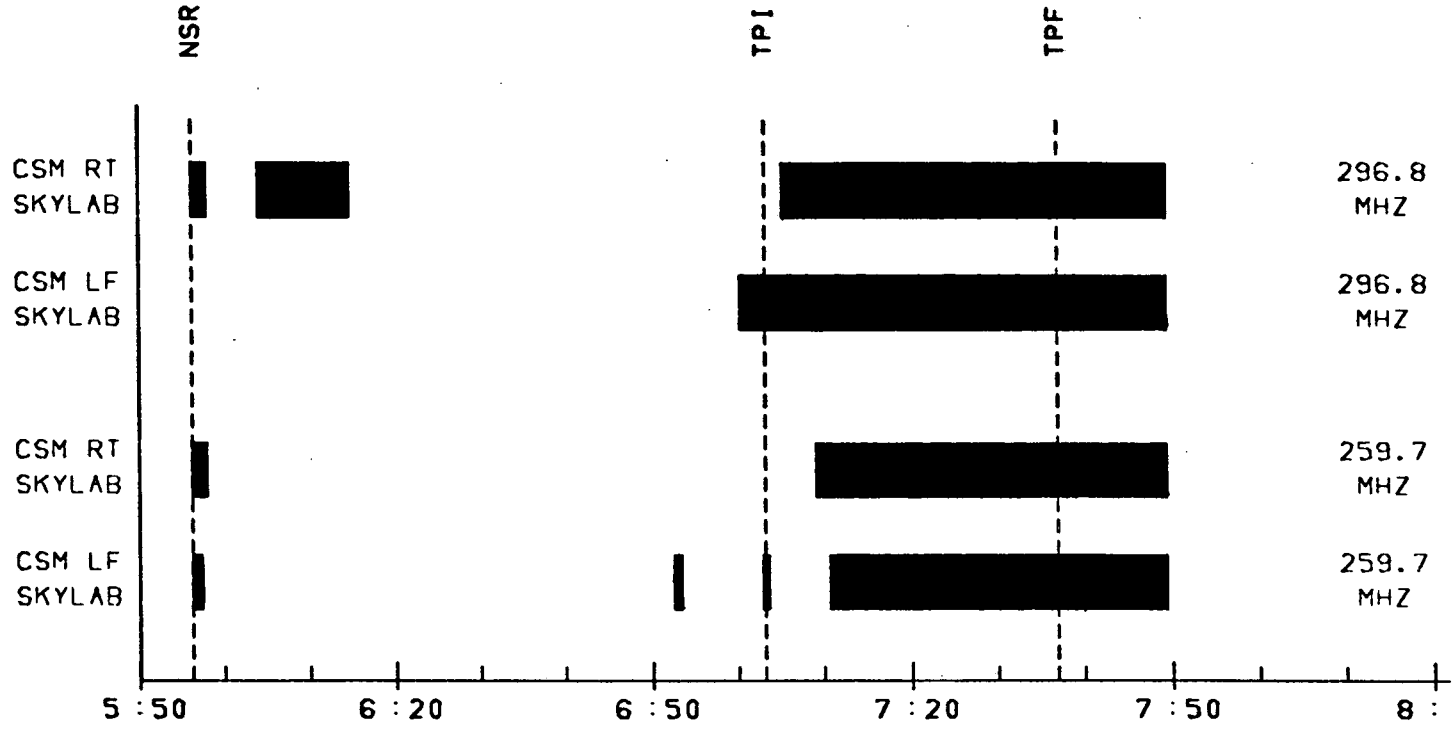

Figure 2. VHF Simplex Link Summary - Minimum Signal (Early TPI)

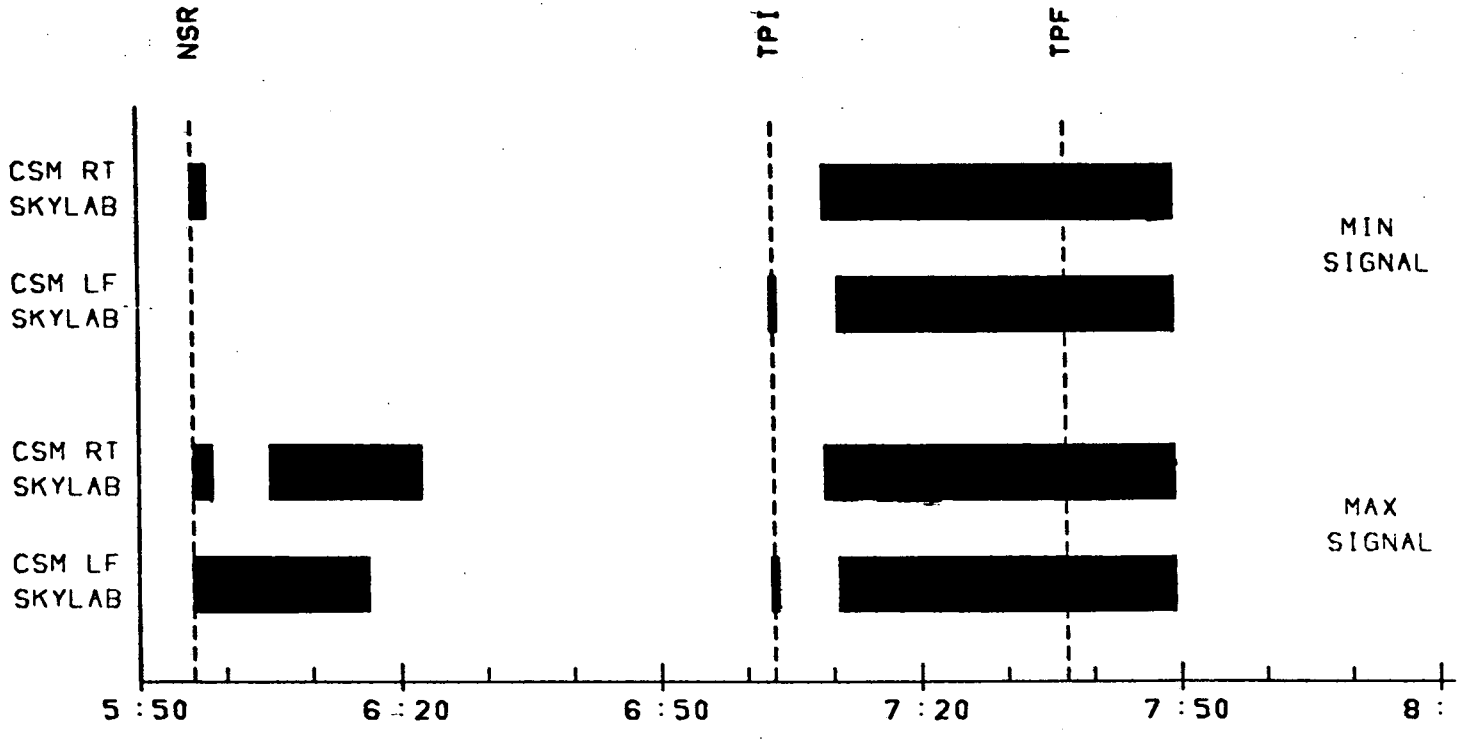

Figure 3. VHF Duplex Link Summary (Early TPI)

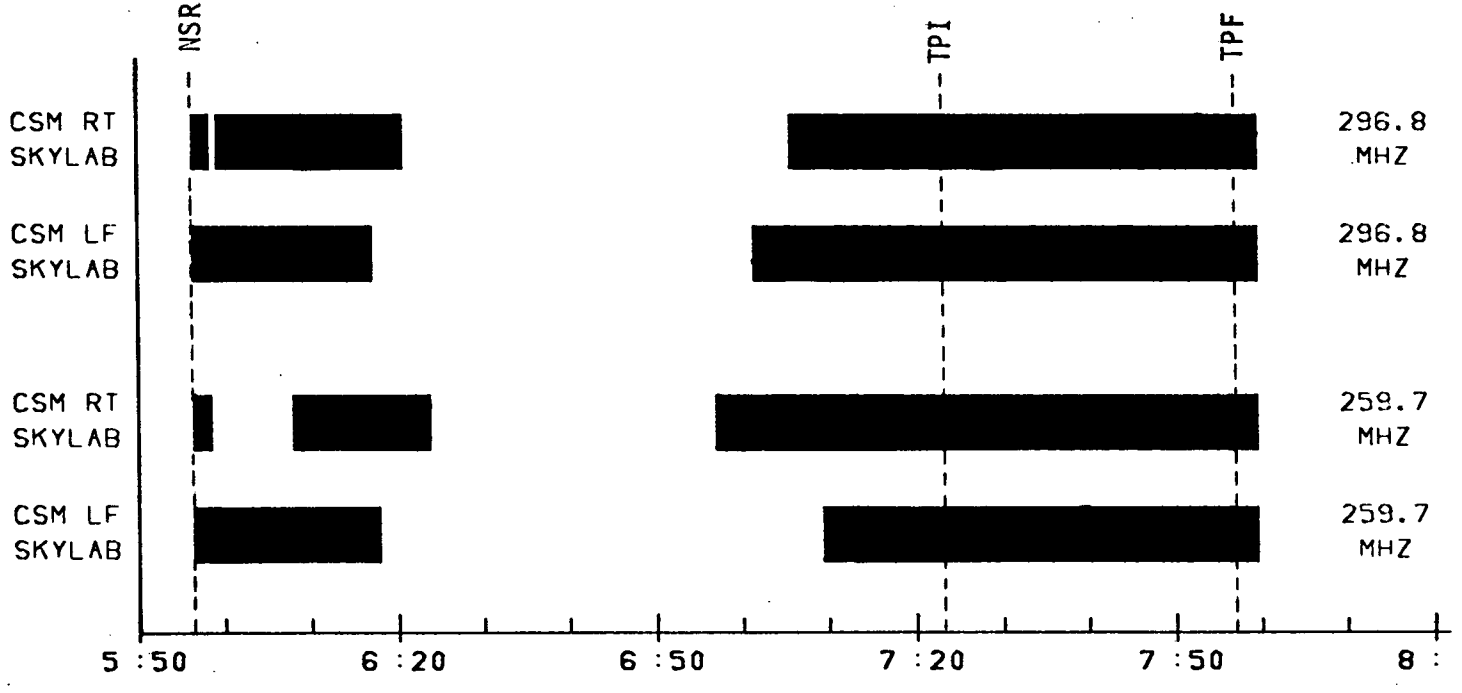

Figure 4. VHF Simplex Link Summary - Maximum Signal (Late TPI)

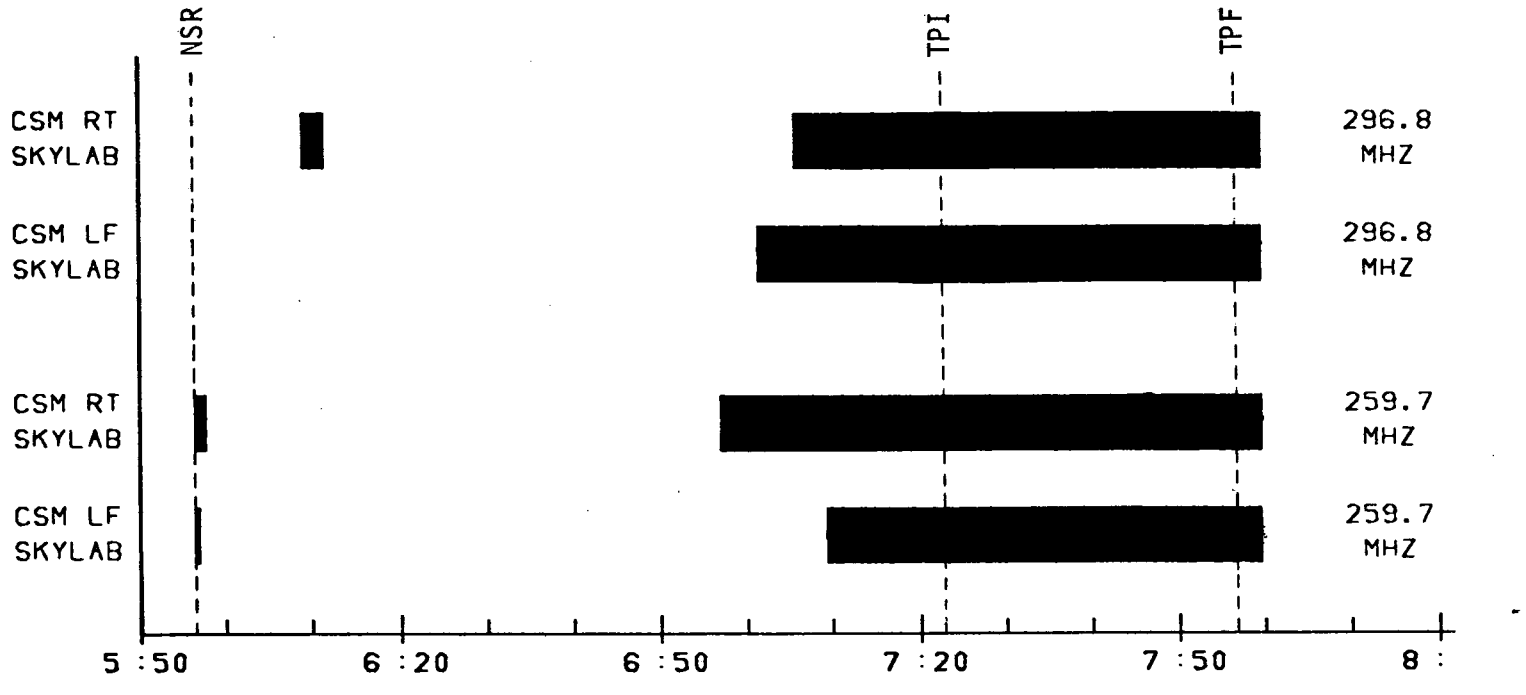

Figure 5. VHF Simplex Link Summary - Minimum Signal (Late TPI)

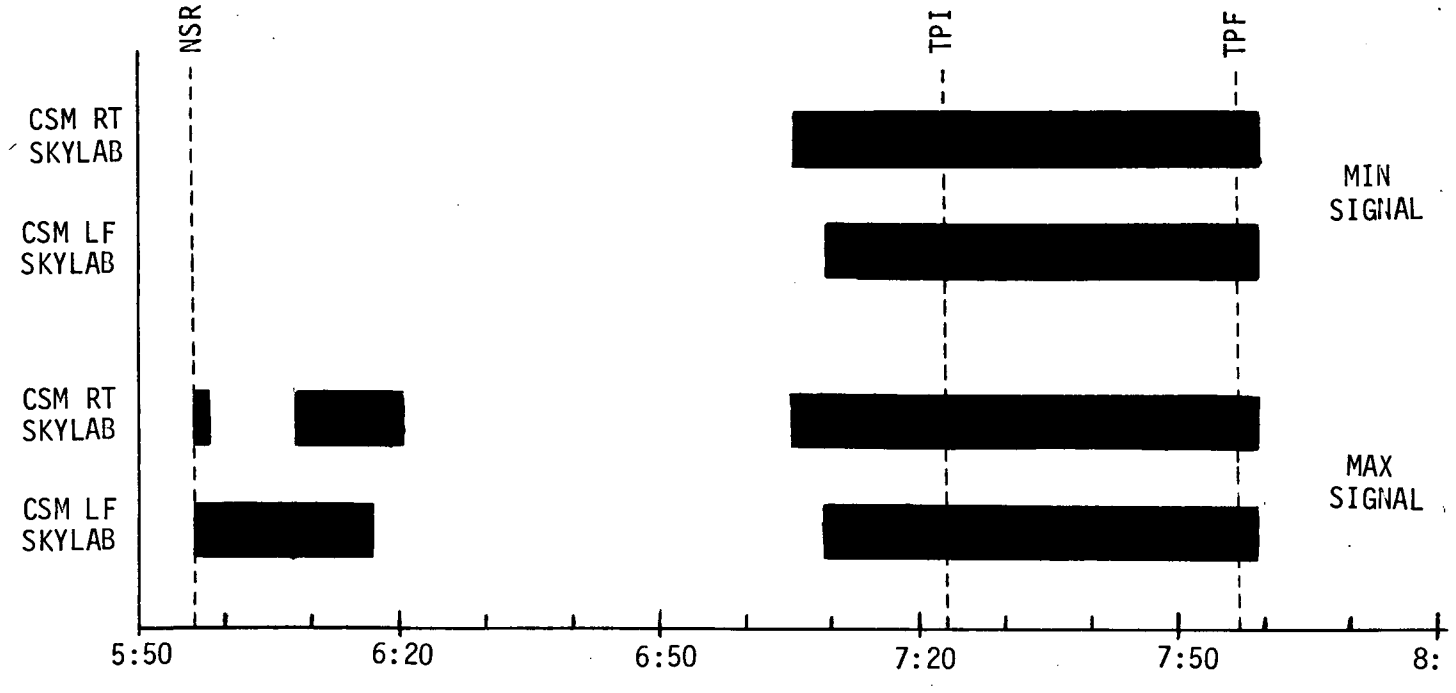

Figure 6. VHF Duplex Link Summary (Late TPI)

3. CONCLUSIONS

Using the criteria of earliest possible acquisitions, latest possible dropouts, greatest overall received power margins, and minimum antenna switching, the CSM right antenna should be selected throughout the entire rendezvous sequence. Using the CSM right antenna, the final tracking period (from near TPI to station keeping) will begin no later than 7:09 g.e.t. for early TPI (7:02 g.e.t.) and 7:07 g.e.t. for late TPI (7:22 g.e.t.). This corresponds to a final acquisition of the ranging function no later than about five minutes after an early TPI maneuver and about 15 minutes prior to a late TPI maneuver.

The predicted time of acquisition for the final tracking period occurs at approximately the same G.E.T. for the early, nominal, and late TPI trajectory cases. This is a consequence of the SWS SI attitude timeline, which is the same for each case. Since the CSM direction from the SWS local horizontal is fairly constant during the latter portion of the rendezvous, the SWS to CSM look angle time history in this interval should be almost unchanged among the cases; the CSM to SWS look angles are fixed by operational constraints. Hence, the primary differences in these trajectories near TPI is vehicle range: for a given g.e.t., the CSM is progressively further from the SWS as TPI is early, nominal, or late. If range effects predominated, then final acquisition could be expected to occur progressively later in g.e.t. as TPI is early, nominal, or late. On the other hand, if SWS antenna gain (beamwidth) effects predominated, then final acquisition could be expected to occur at approximately the same g.e.t. for each case. Consequently, the SWS attitude is the controlling factor in determining at which g.e.t. the final acquisition will occur.

APPENDIX A
SL-1/SL-3 SKYLAB TIMELINE PLOTS (EARLY AND LATE TPI)

The figures in this Appendix present, as functions of mission time, plots of the range between the CSM and the SWS (Figures 7 and 24), the CSM and SWS look angles (Figures 8, 9, 25, and 26), the CSM and SWS antenna gains (Figures 10-15 and 27-32), and the maximum and minimum received power variations on each link (Figures 16-23 and 33-40) on each link. The early TPI plots appear as Figures 7-23 followed by the late TPI plots (Figures 24-40).

In the look angle plots, the ϕ curve is plain, and the θ curve is marked by "+" ticks at each data point. Both curves, as well as all of the curves shown in this appendix, consist of straight lines connecting the data points. The ticks on the θ curves serve as a guide for the time location of the processed data points and their relative spacing.

All look angles are plotted in degrees with θ ranging from 0° to 180° and ϕ ranging from 0° to 360°. A sudden jump in the ϕ curve from nearly 360° to 0° or vice versa is merely a result of the plotting limits, and the curve may be considered continuous. Also, as the θ curve approaches 0° or 180°, the ϕ curve may be required to change rapidly by 180° due to the nature of spherical coordinates.

The CSM and SWS antenna gain plots presented in this appendix are based on antenna patterns [2] derived from scale model measurements. As noted in [6] , these patterns, rectangular projections describing the total power radiated to a theoretical sphere surrounding the antenna, are taken in 1 dB increments in amplitude and 2° increments in θ and ϕ (angular distribution).

The received power plots demonstrate the maximum and minimum received power for each ranging link. Maximum received power plots represent the case where the multipath signal is added in-phase with the direct path signal, while minimum received power plots represent out-of-phase multipath signal contributions. On each of the plots the VHF ranging acquisition threshold is shown as -104 dBm and the ranging function tracking dropout threshold as -107 dBm.

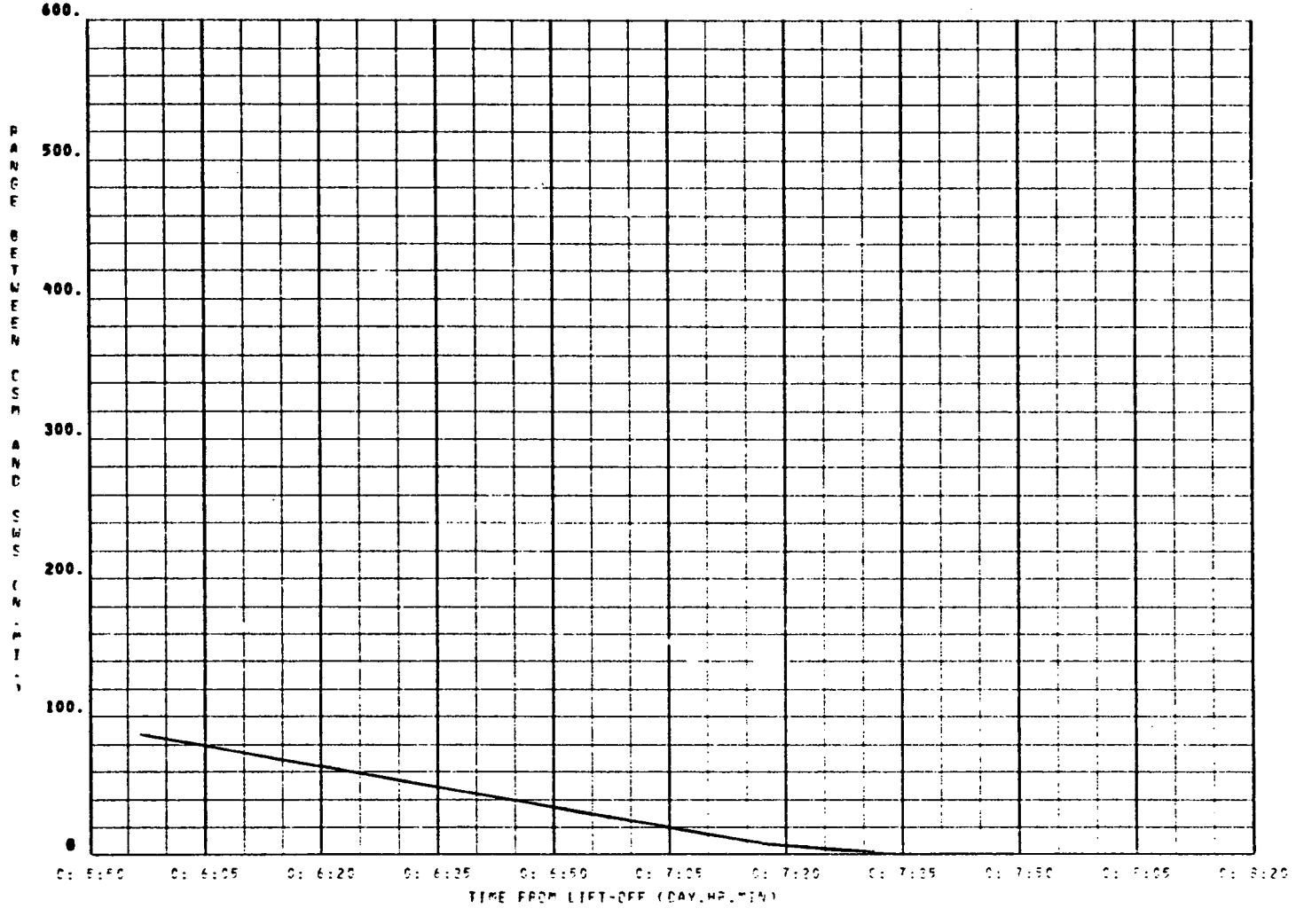

Figure 7. Range Between CSM and SWS (Early TPI)

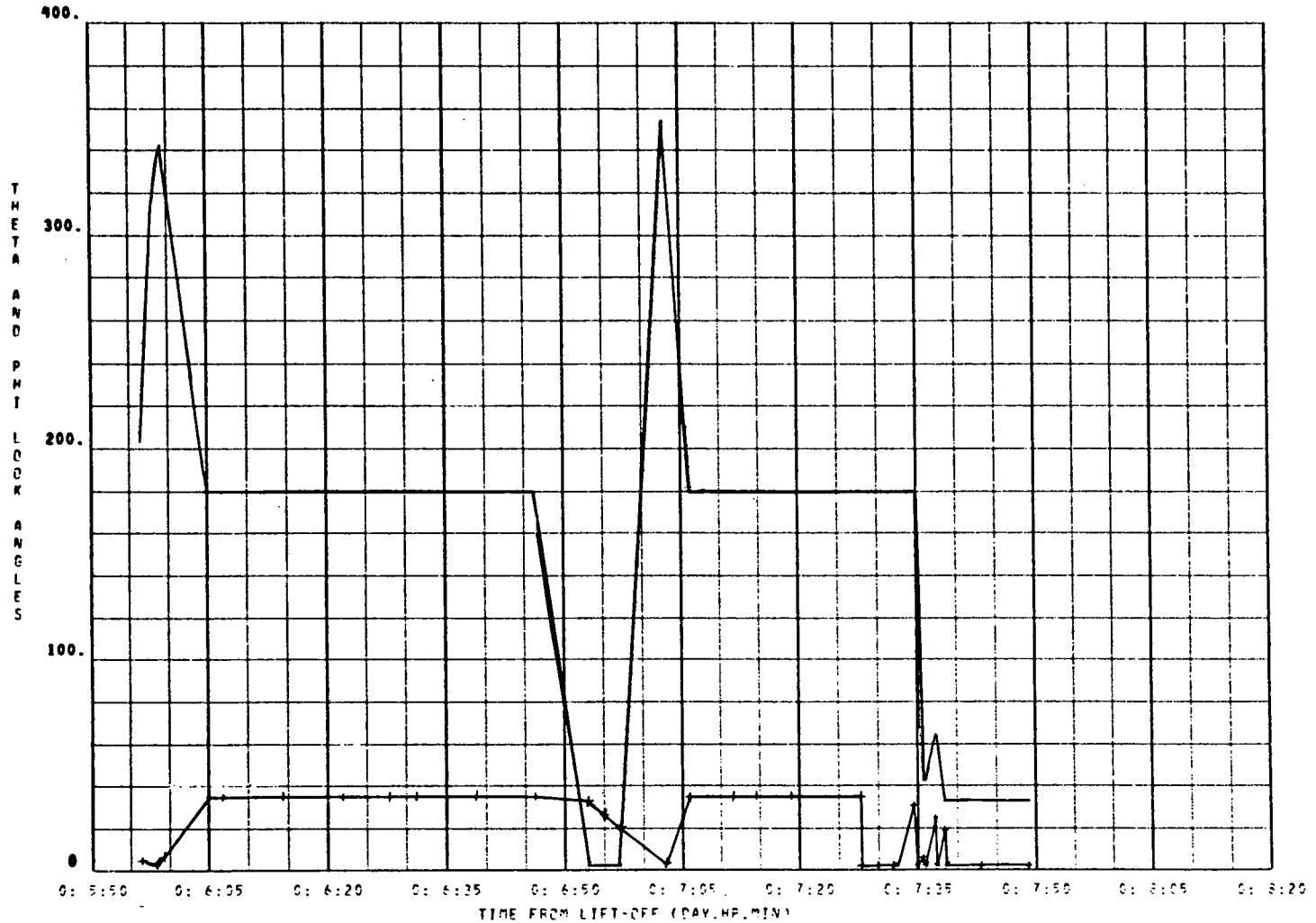

Figure 8. Look Angles CSM to SWS (Early TPI)

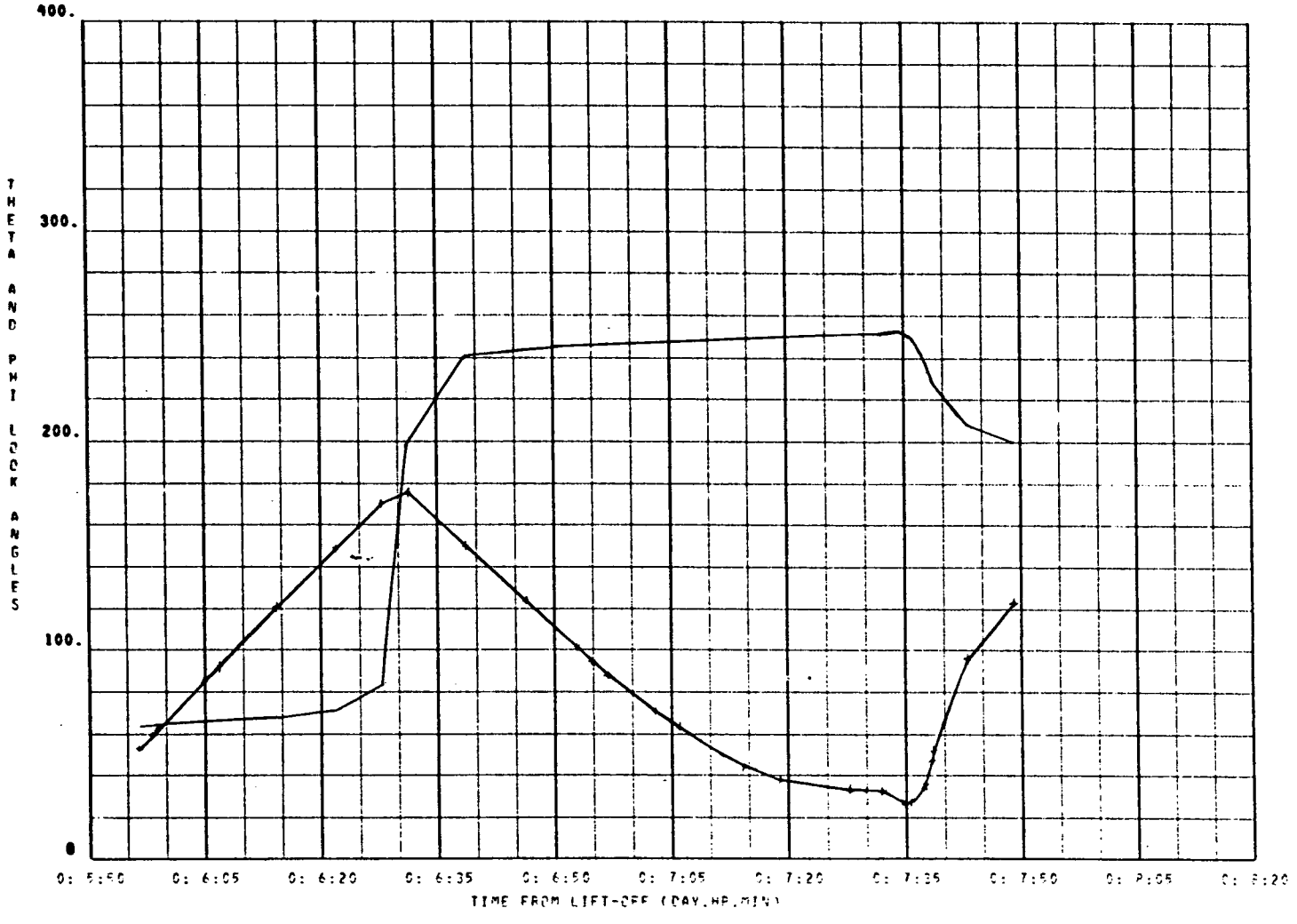

Figure 9. Look Angles SWS to CSM (Early TPI)

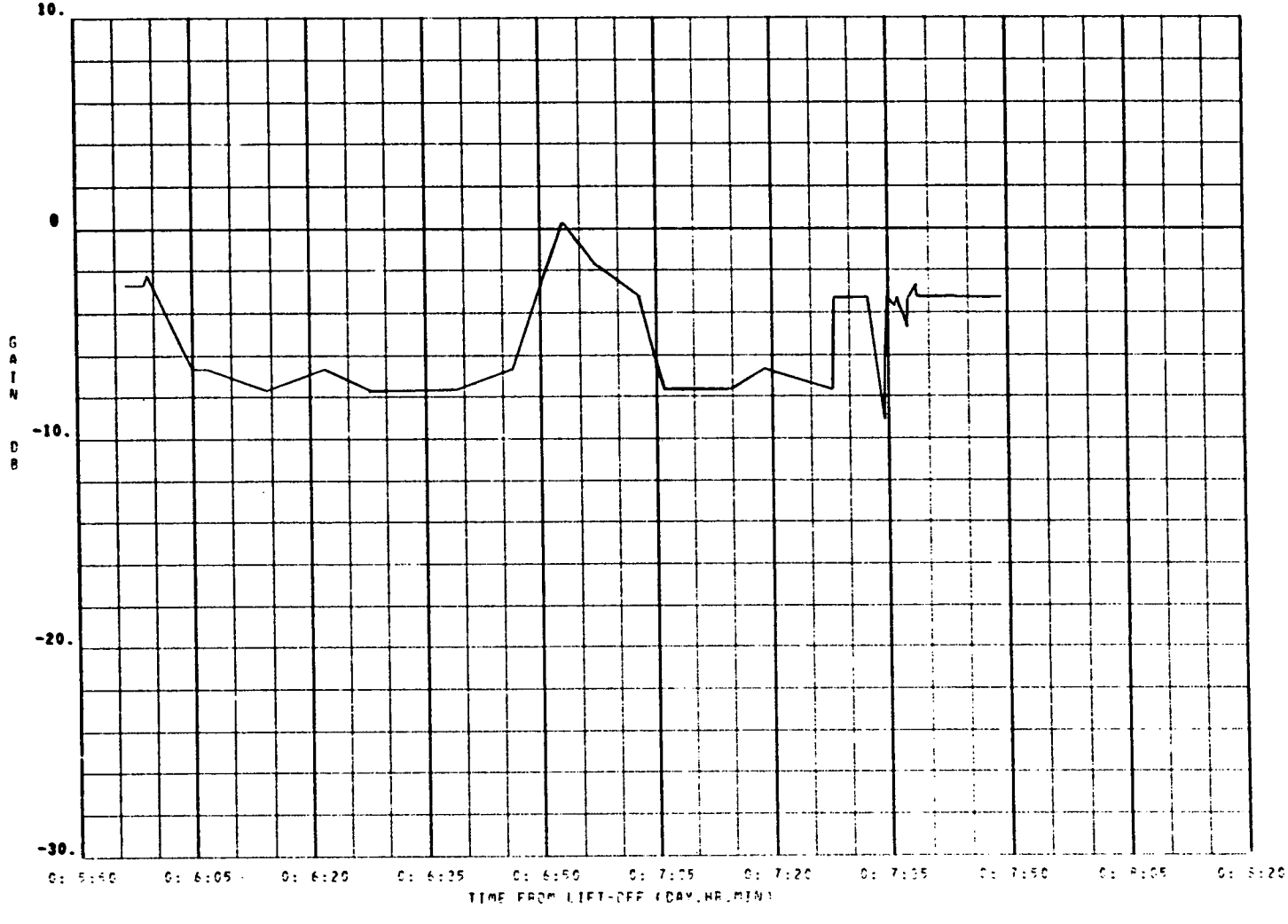

Figure 10. CSM Left Antenna Gain - 259.7 MHz (Early TPI)

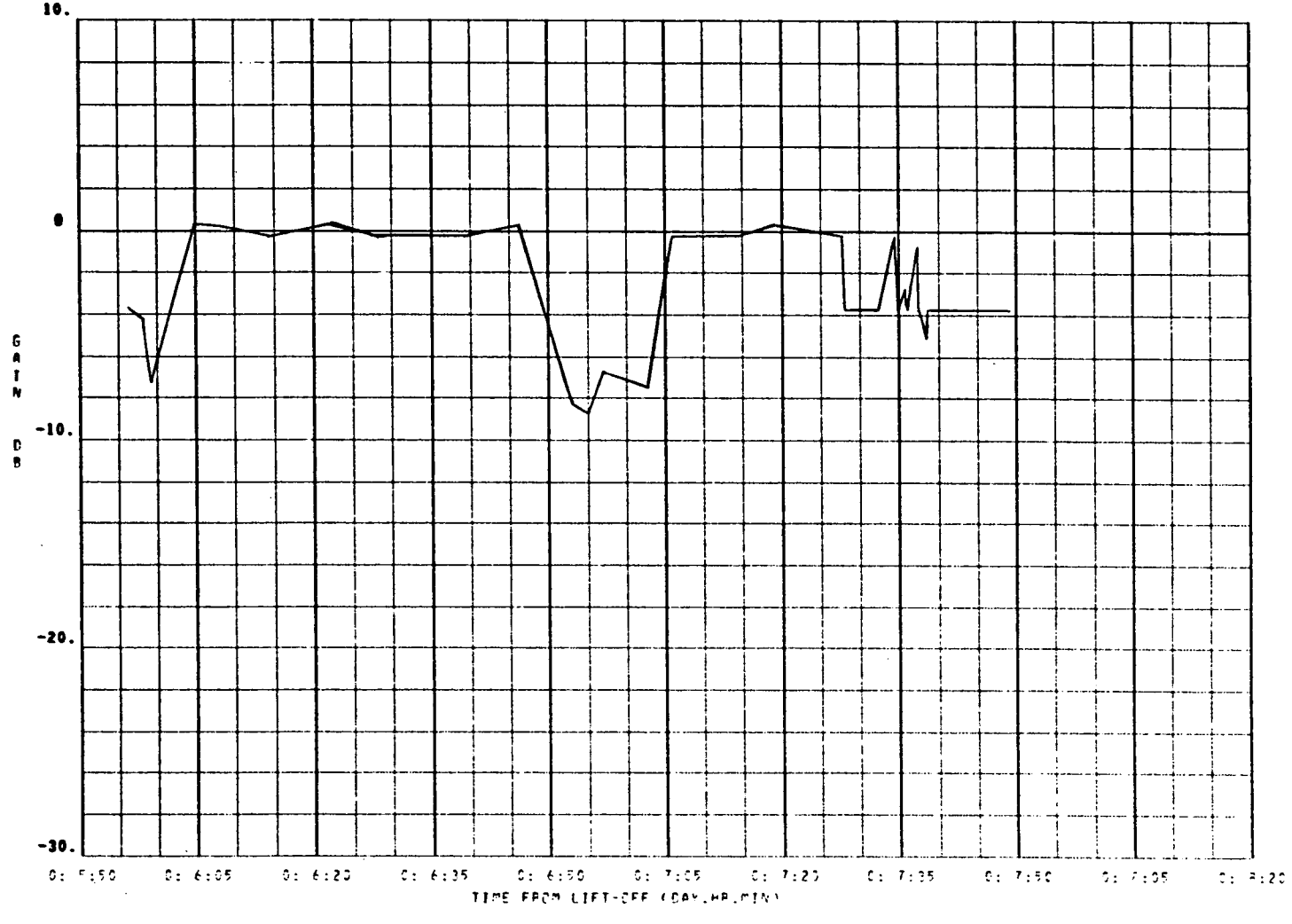

Figure 11. CSM Right Antenna Gain - 259.7 MHz (Early TPI)

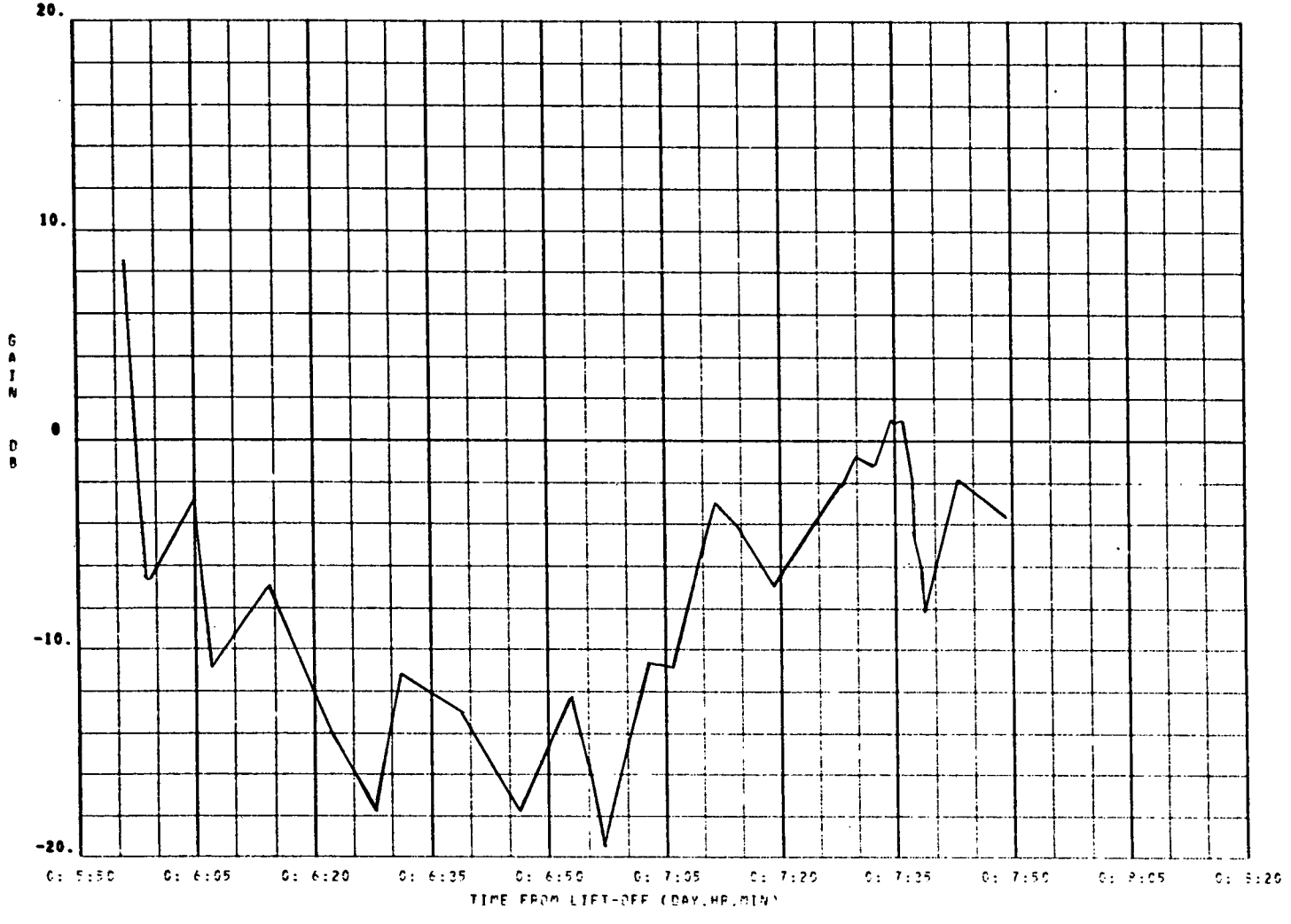

Figure 12. SWS Antenna Gain - 259.7 MHz (Early TPI)

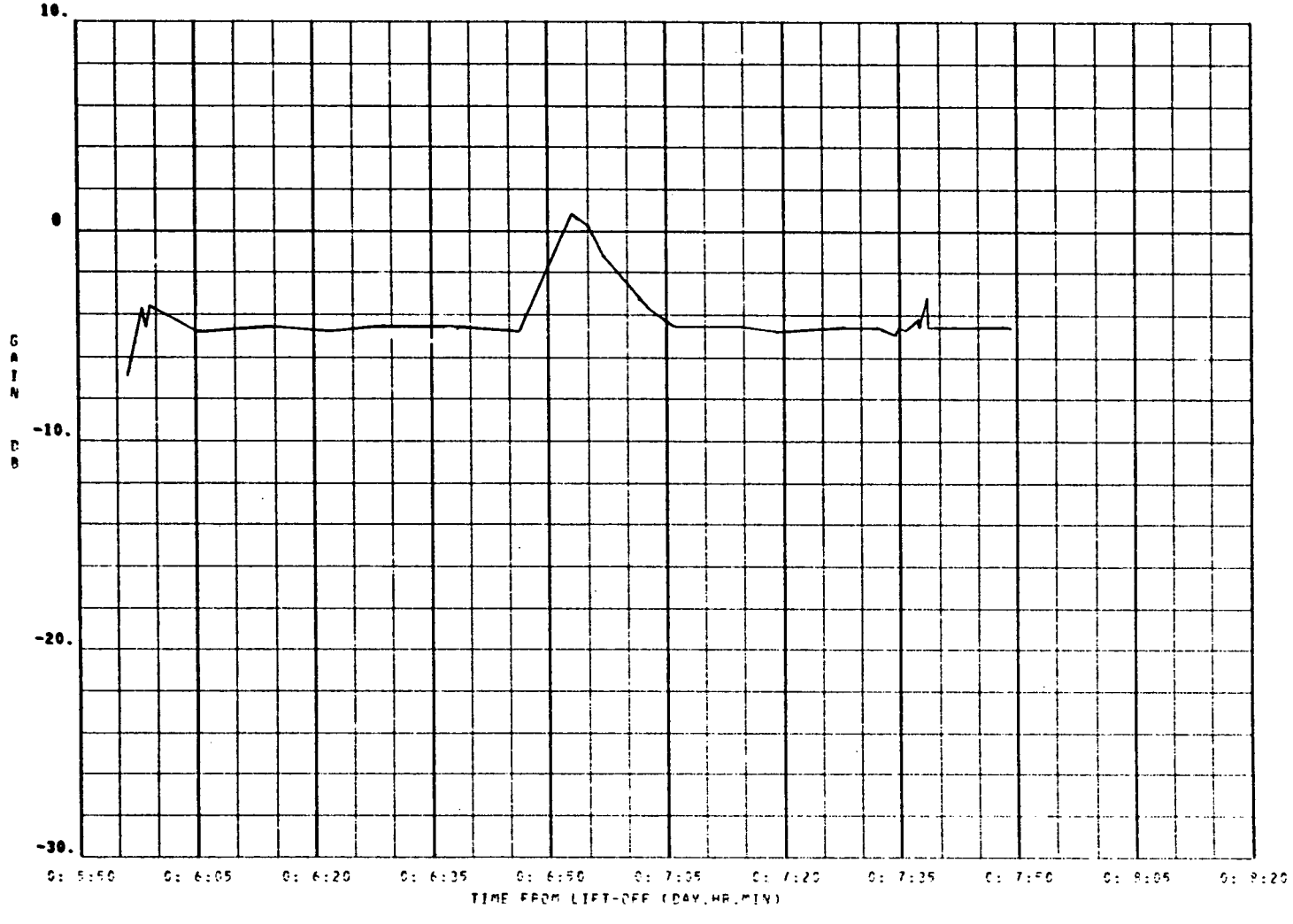

Figure 13. CSM Left Antenna Gain 296.8 MHz (Early TPI)

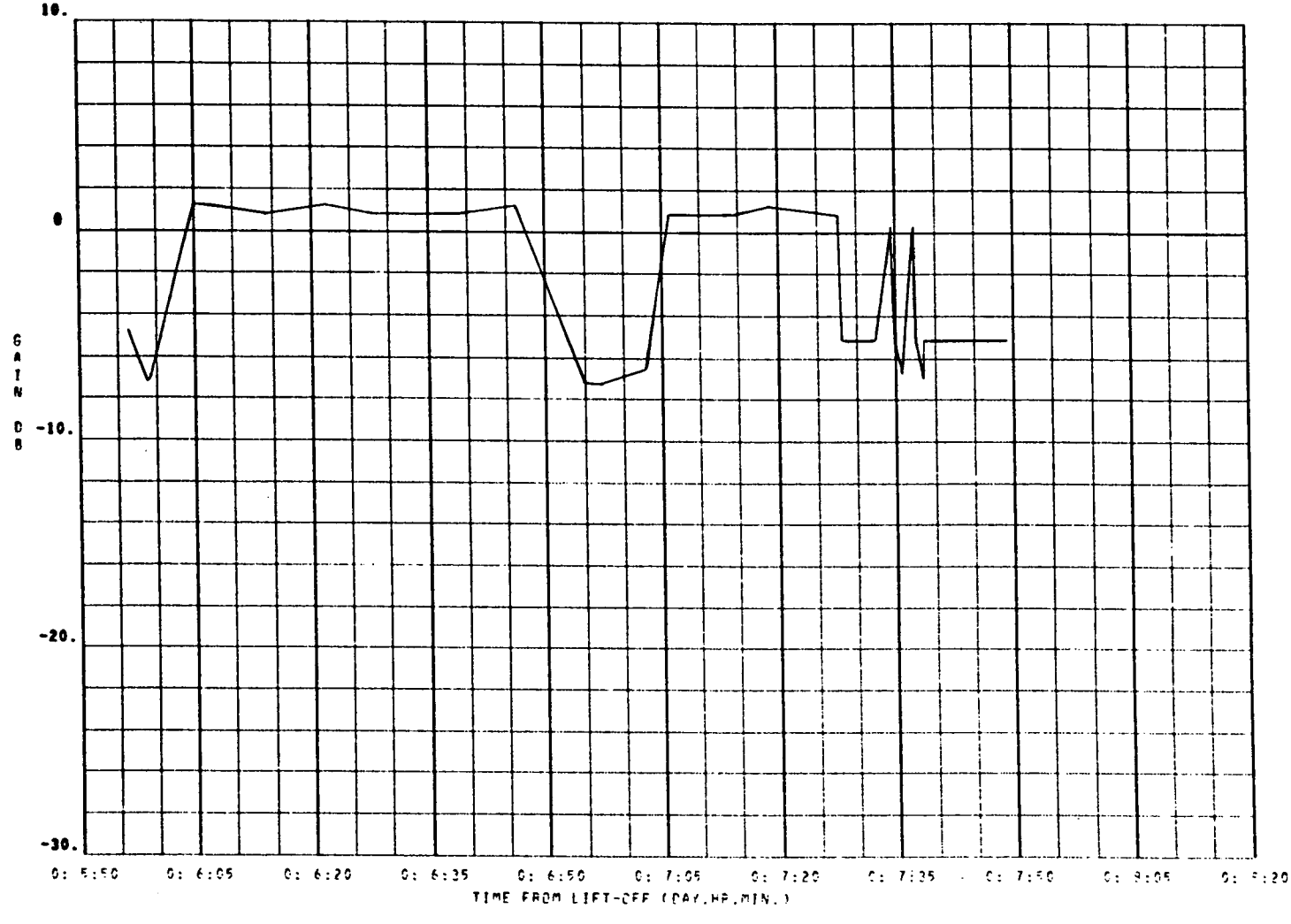

Figure 14. CSM Right Antenna Gain 296.8 MHz (Early TPI)

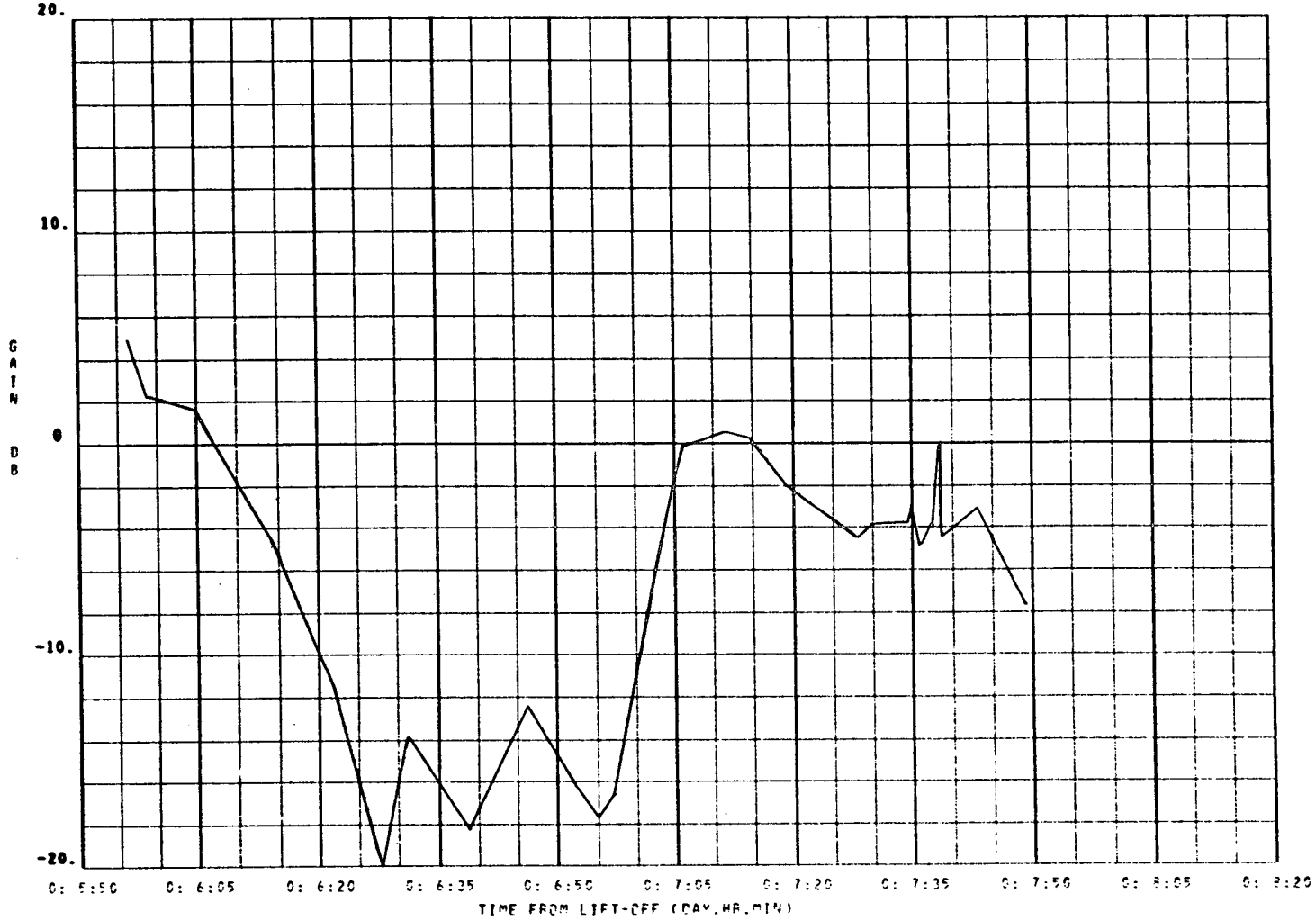

Figure 15. SWS Antenna Gain 296.8 MHz (Early TPI)

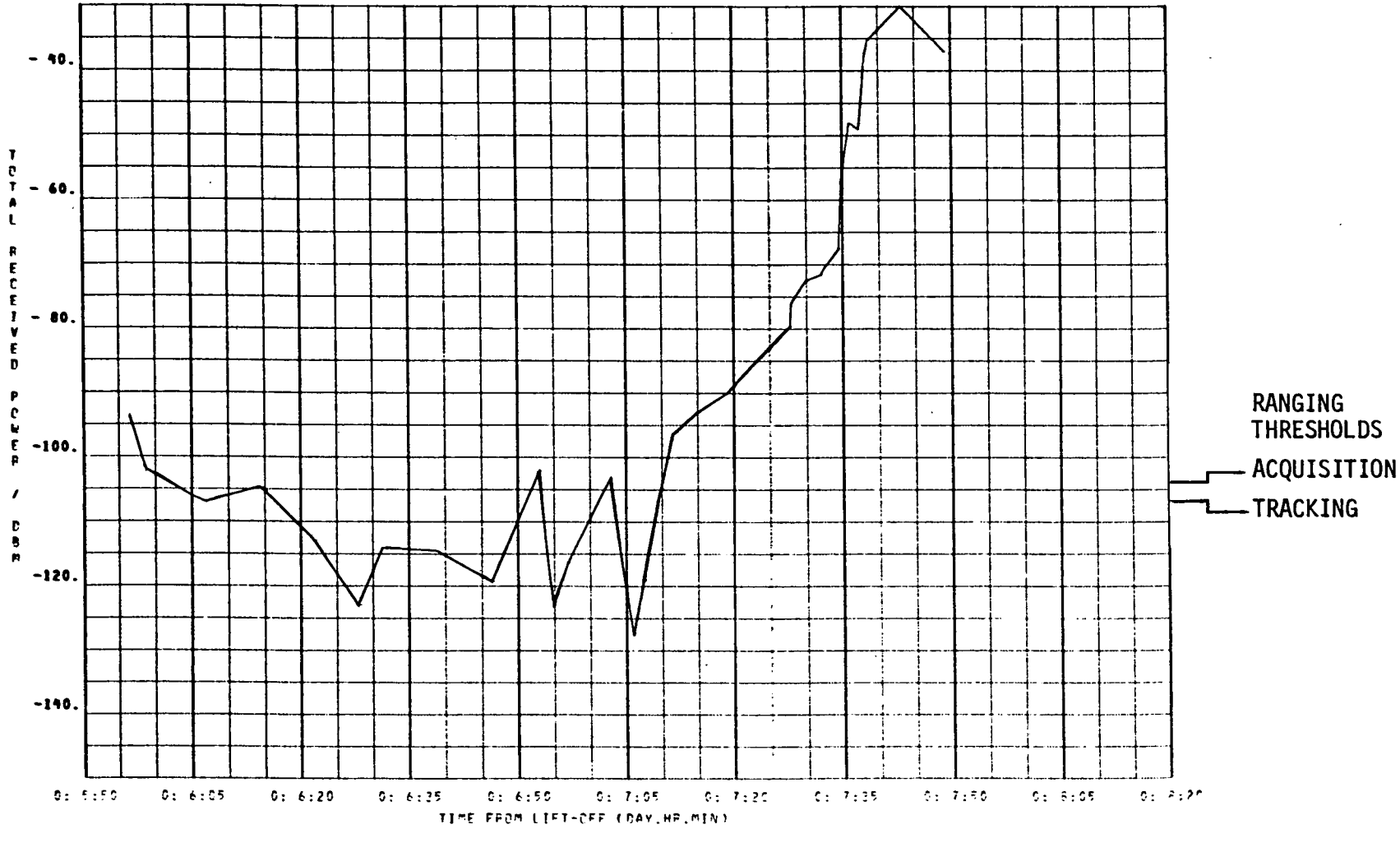

Figure 16. Maximum Received Power - 259.7 MHz - CSM Left and SWS Helix (Early TPI)

Figure 17. Minimum Received Power - 259.7 MHz - CSM Left and SWS Helix (Early TPI)

Figure 18. Maximum Received Power - 259.7 MHz - CSM Right and SWS Helix (Early TPI)

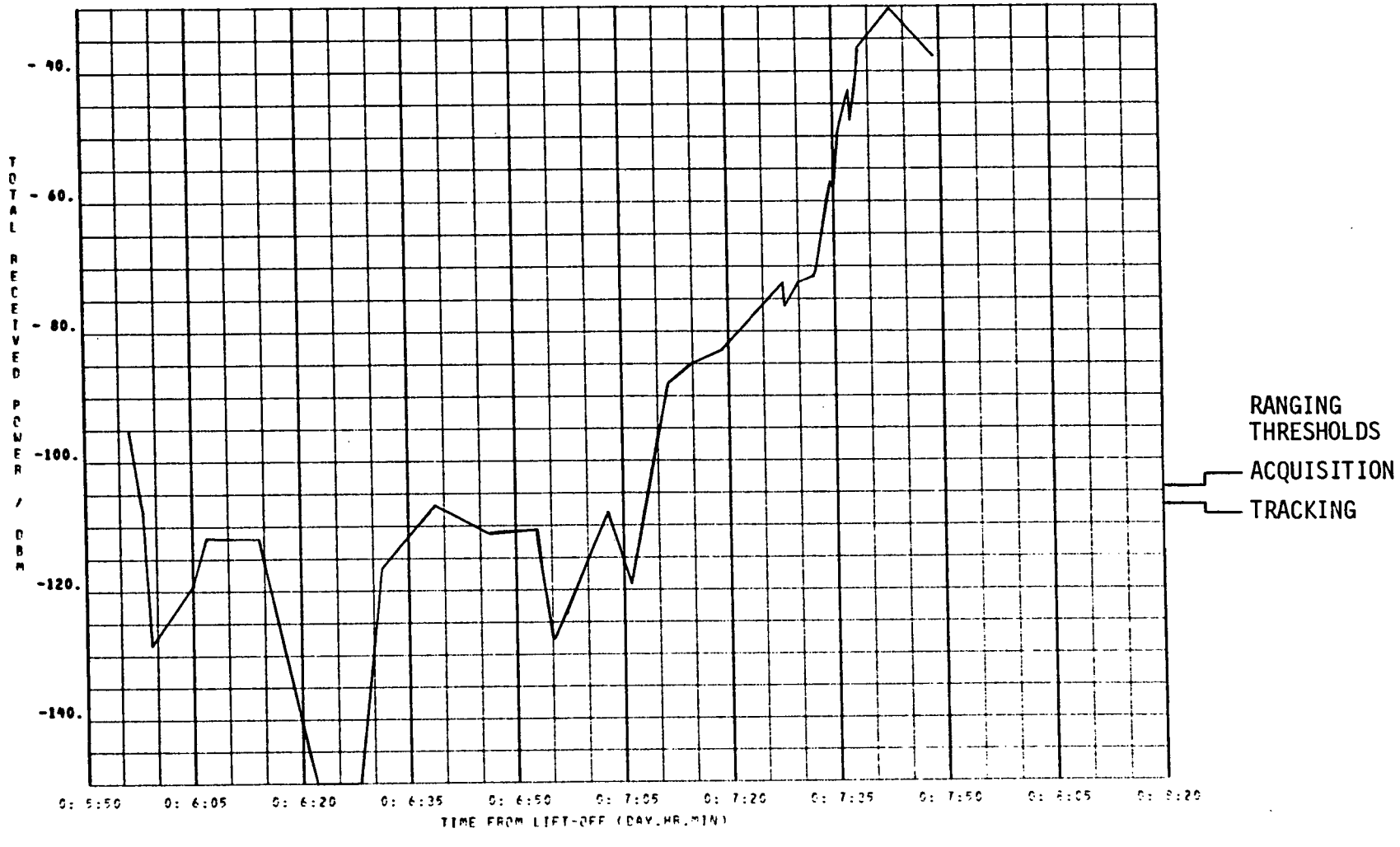

Figure 19. Minimum Received Power - 259.7 MHz - CSM Right and SWS Helix (Early TPI)

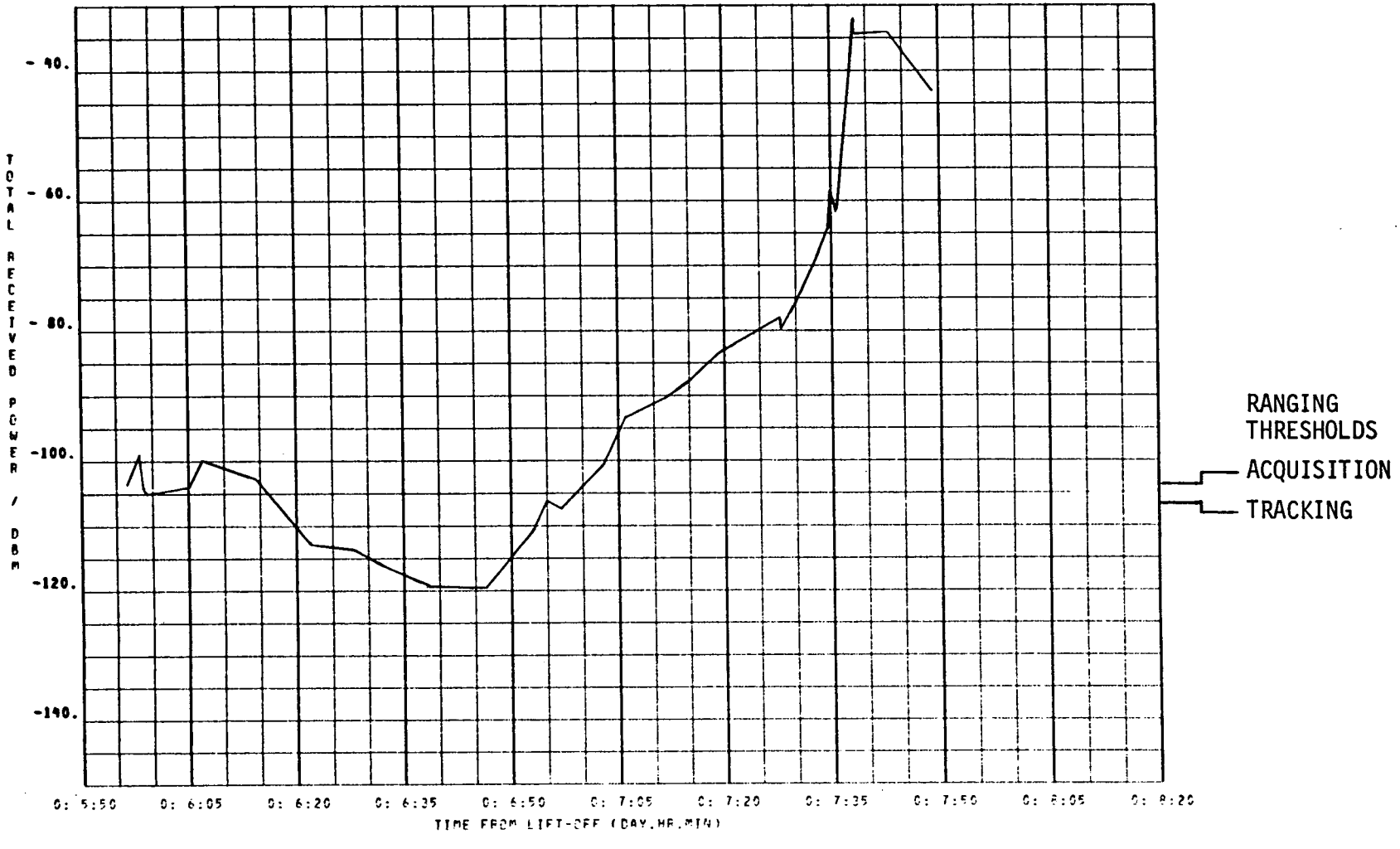

Figure 20. Maximum Received Power - 296.8 MHz - CSM Left and SWS Helix (Early TPI)

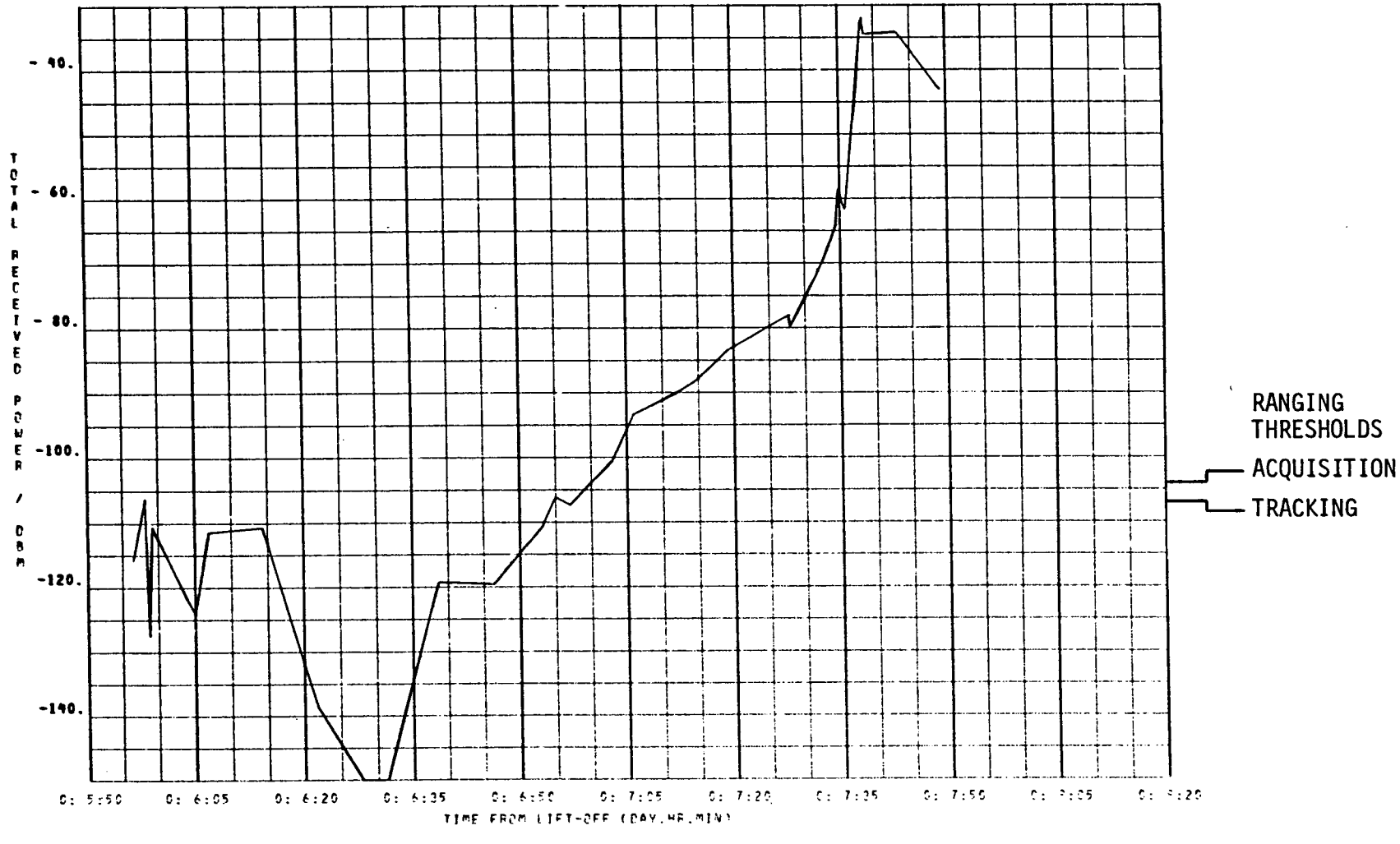

Figure 21. Minimum Received Power - 296.8 MHz - CSM Left and SWS Helix (Early TPI)

Figure 22. Maximum Received Power - 296.8 MHz - CSM Right and SWS Helix (Early TPI)

Figure 23. Minimum Received Power - 296.8 MHz - CSM Right and SWS Helix (Early TPI)

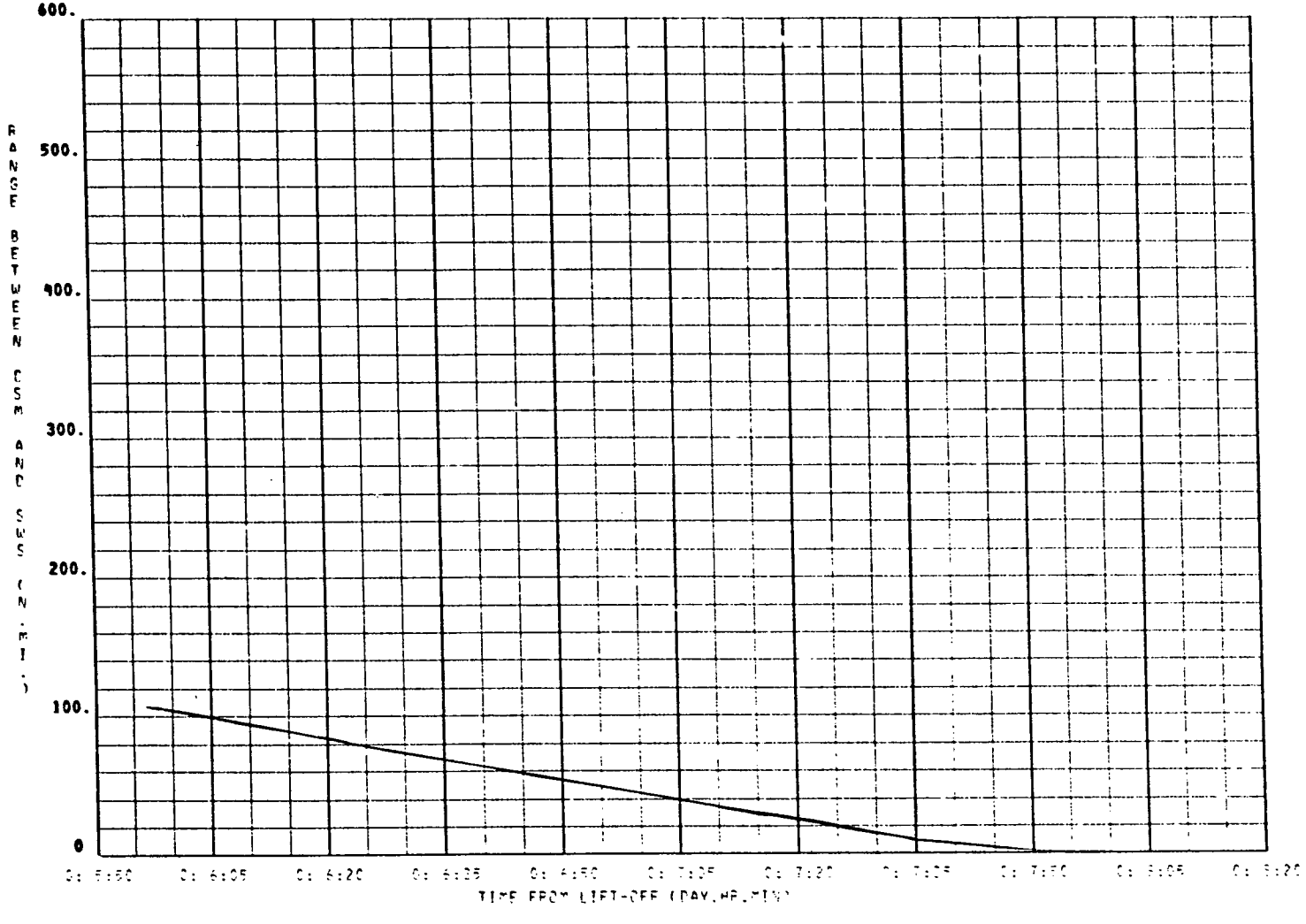

Figure 24. Range Between CSM and SWS (Late TPI)

Figure 25. Look Angles CSM to SWS (Late TPI)

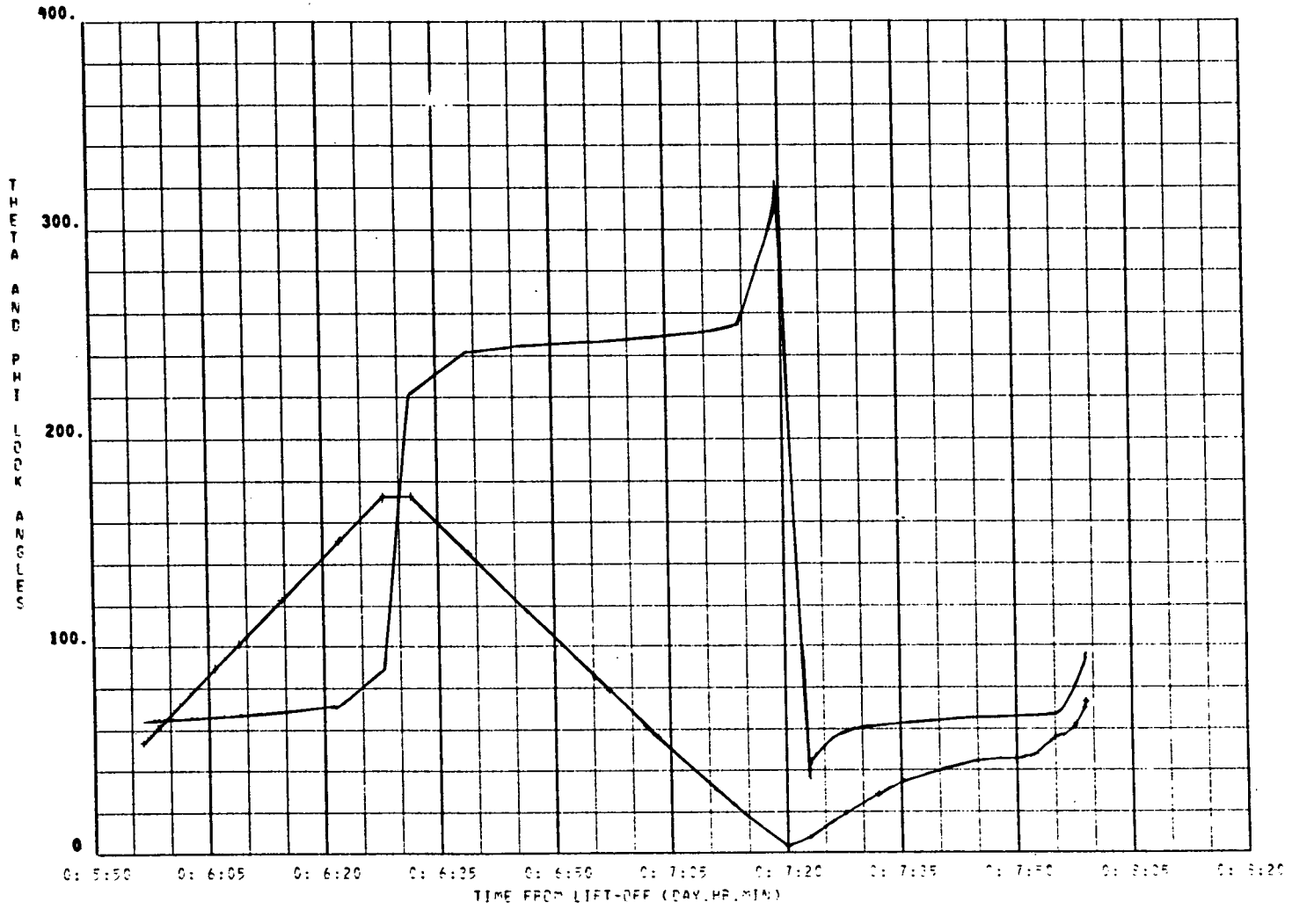

Figure 26. Look Angles SWS to CSM (Late TPI)

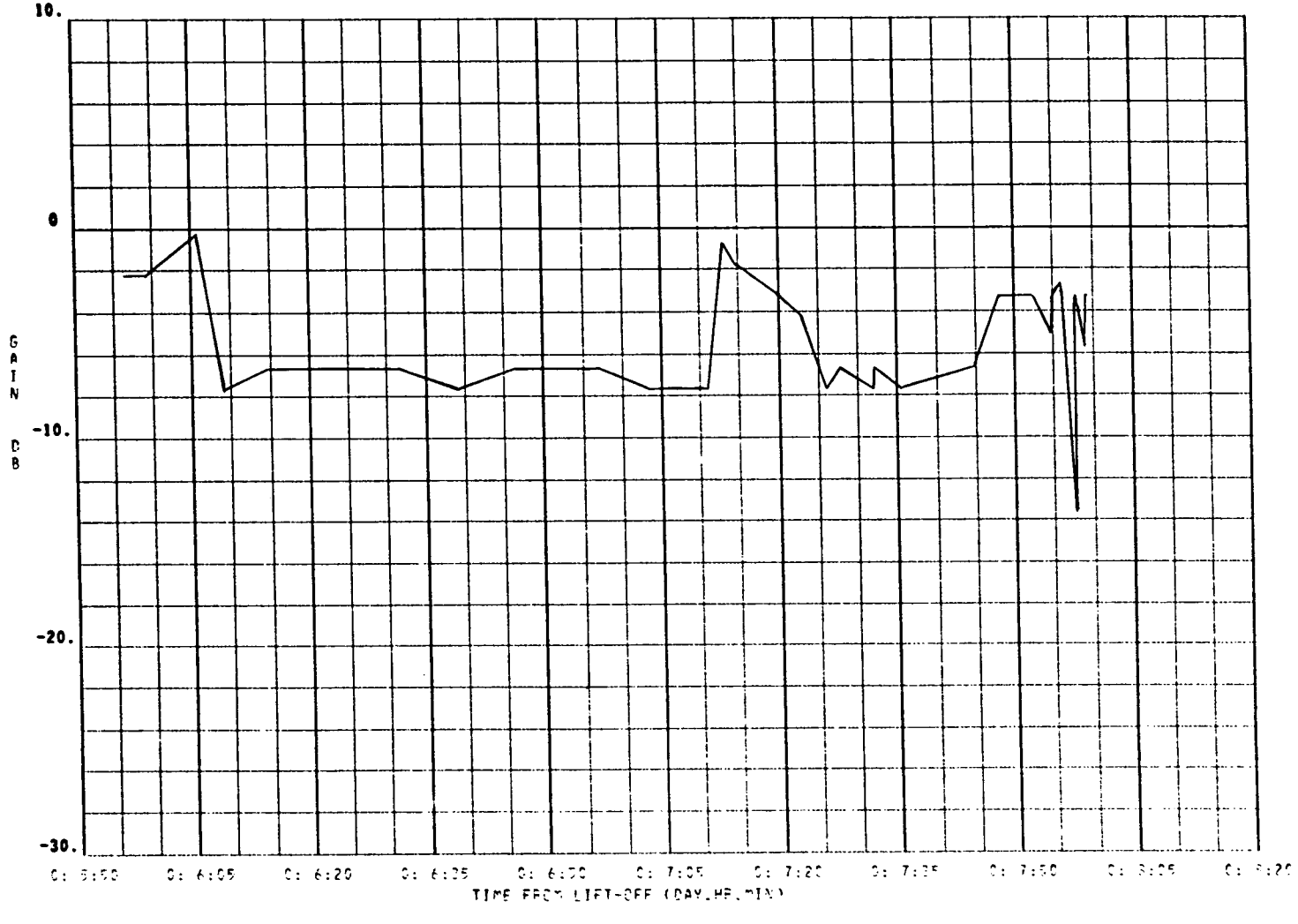

Figure 27. CSM Left Antenna Gain - 259.7 MHz (Late TPI)

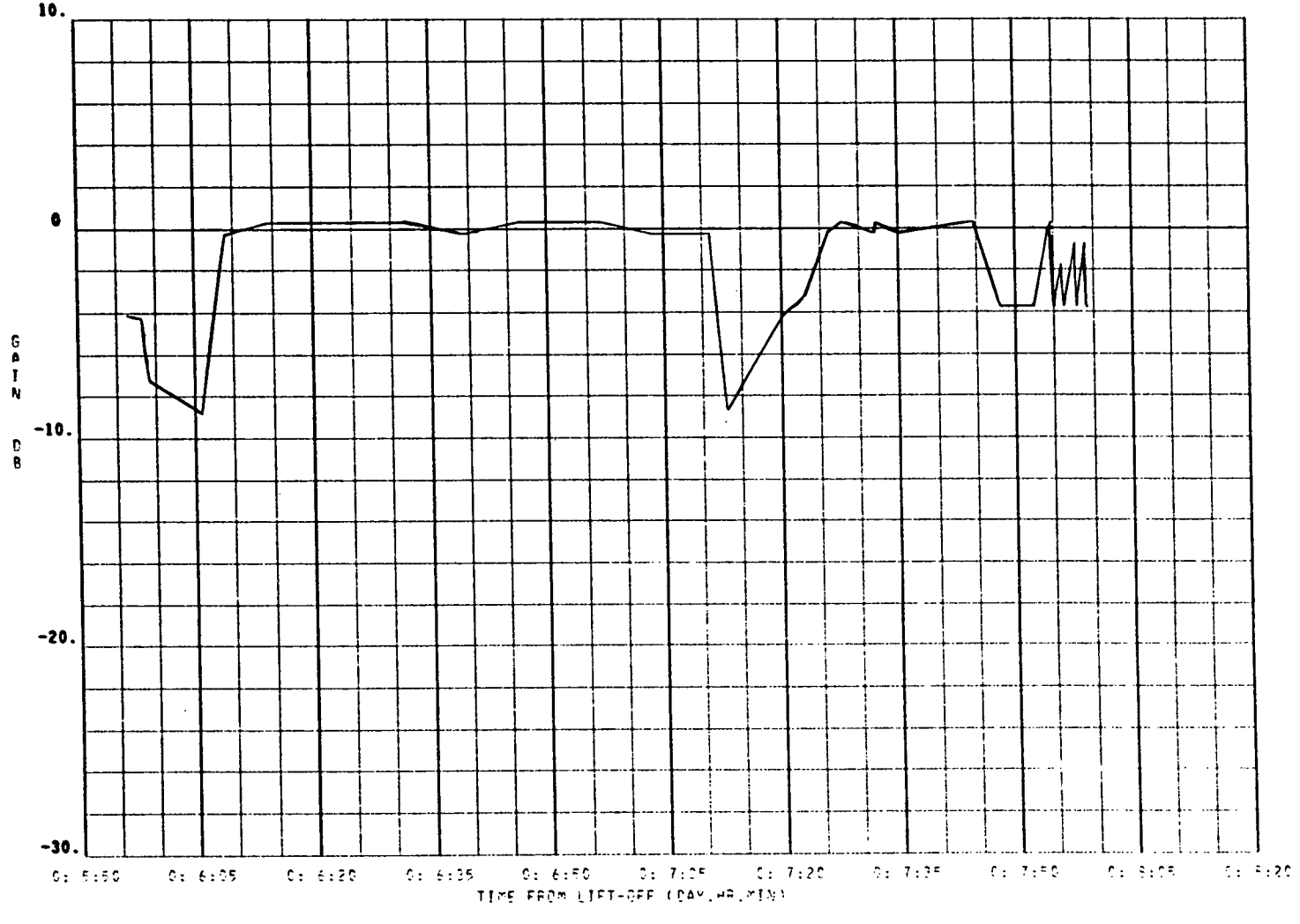

Figure 28. CSM Right Antenna Gain - 259.7 MHz (Late TPI)

Figure 29. SWS Antenna Gain - 259.7 MHz (Late TPI)

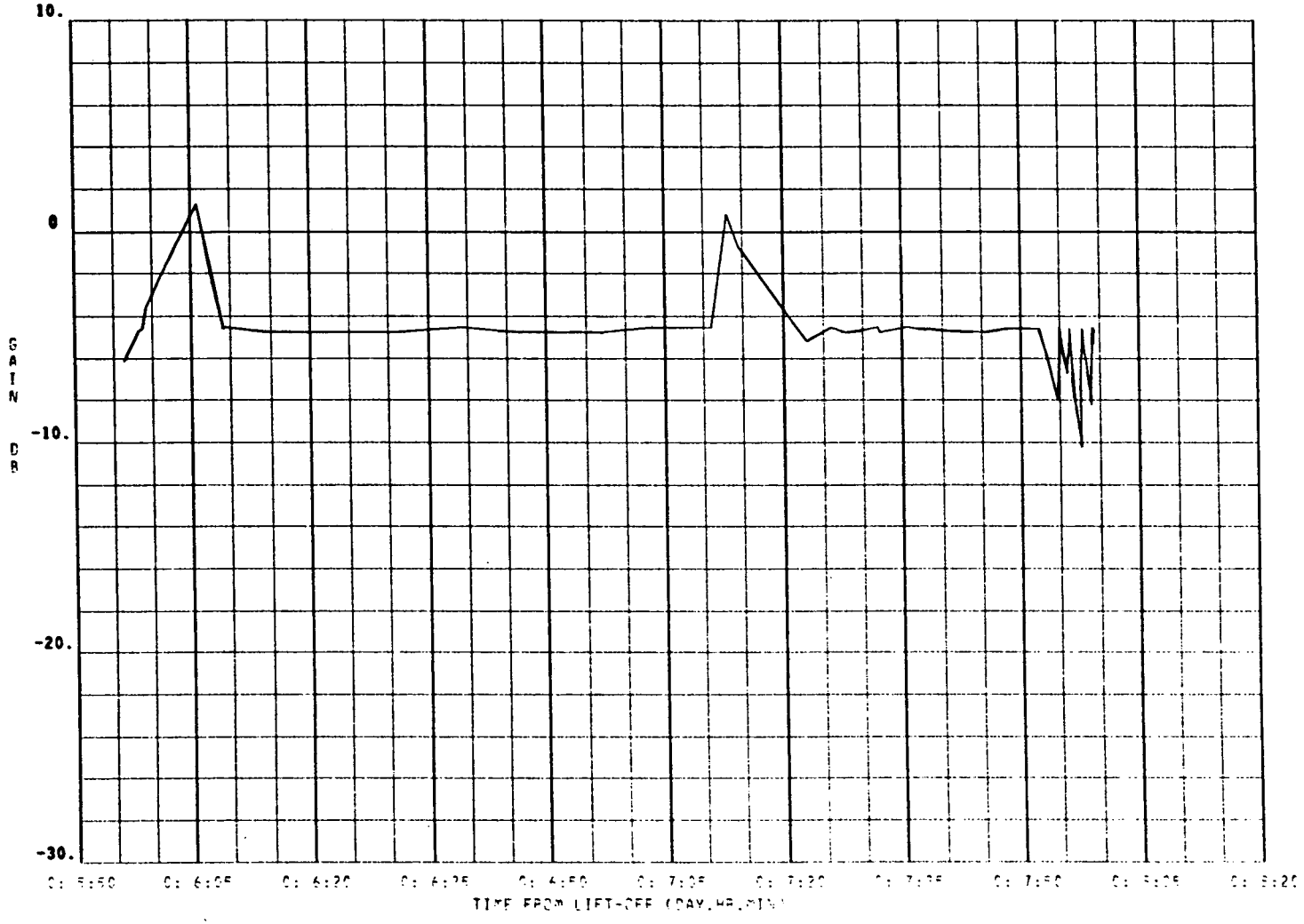

Figure 30. CSM Left Antenna Gain - 296.8 MHz (Late TPI)

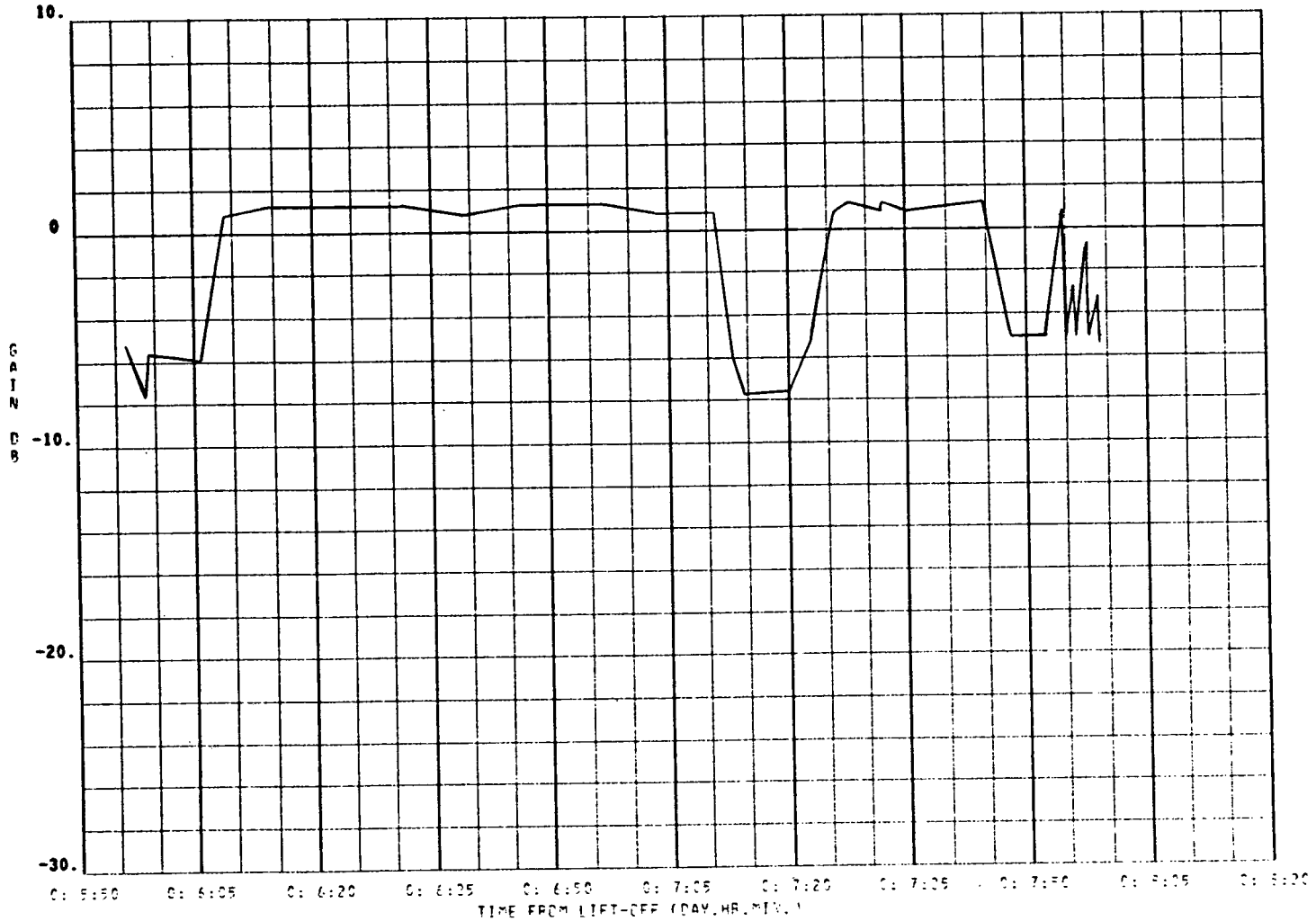

Figure 31. CSM Right Antenna Gain - 296.8 MHz (Late TPI)

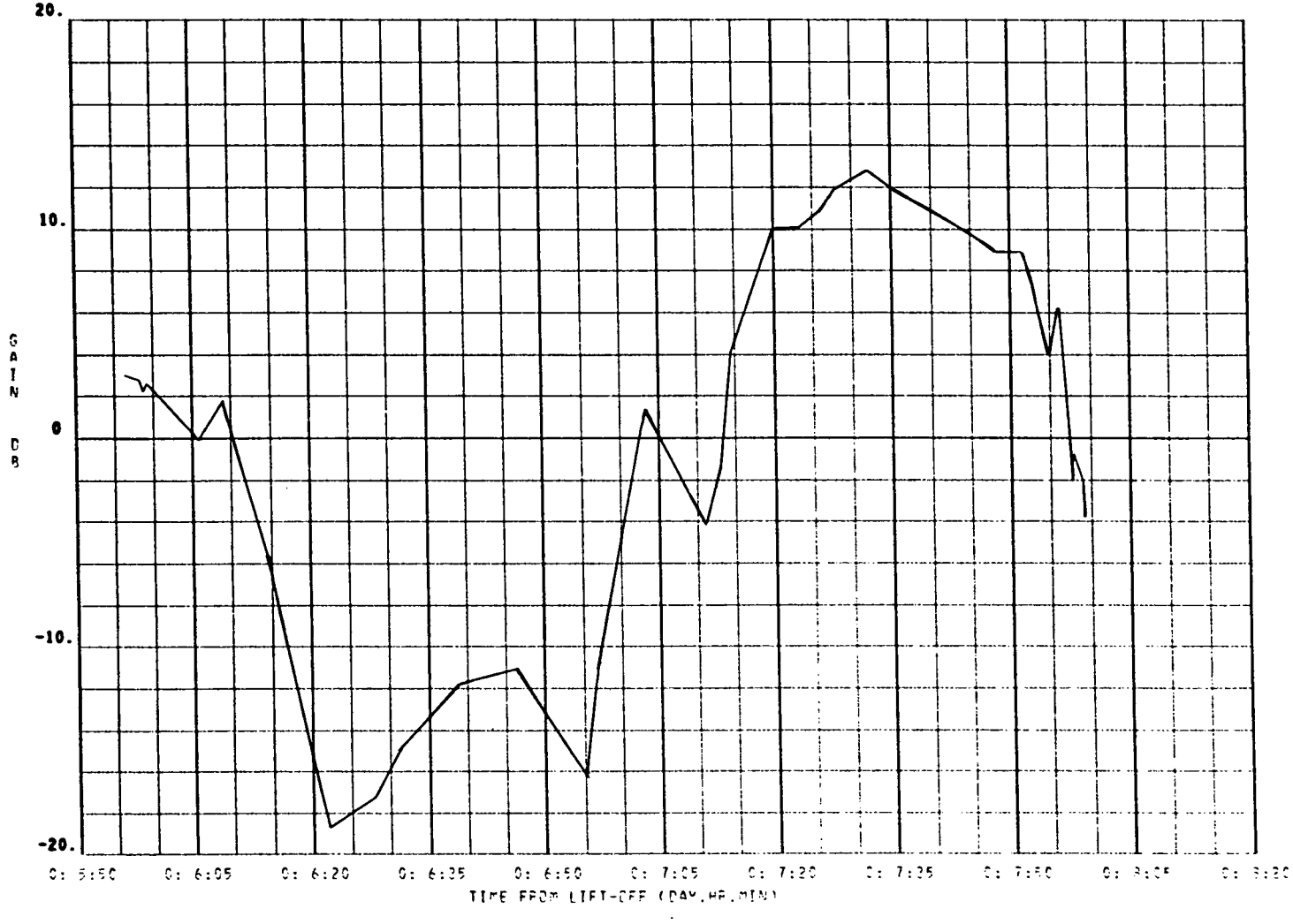

Figure 32. SWS Antenna Gain - 296.8 MHz (Late TPI)

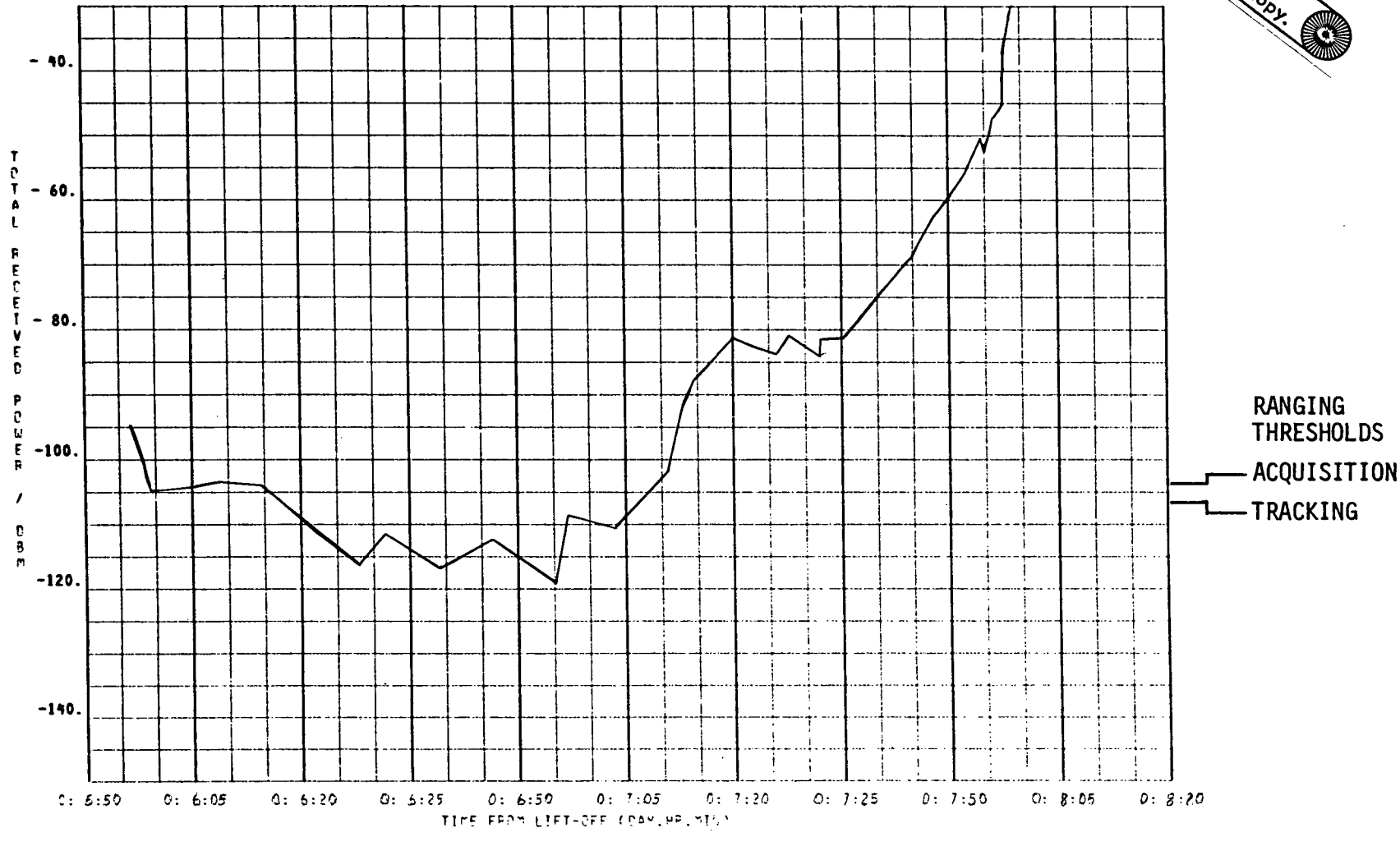

Figure 33. Maximum Received Power - 259.7 MHz - CSM Left and SWS Helix (Late TPI)

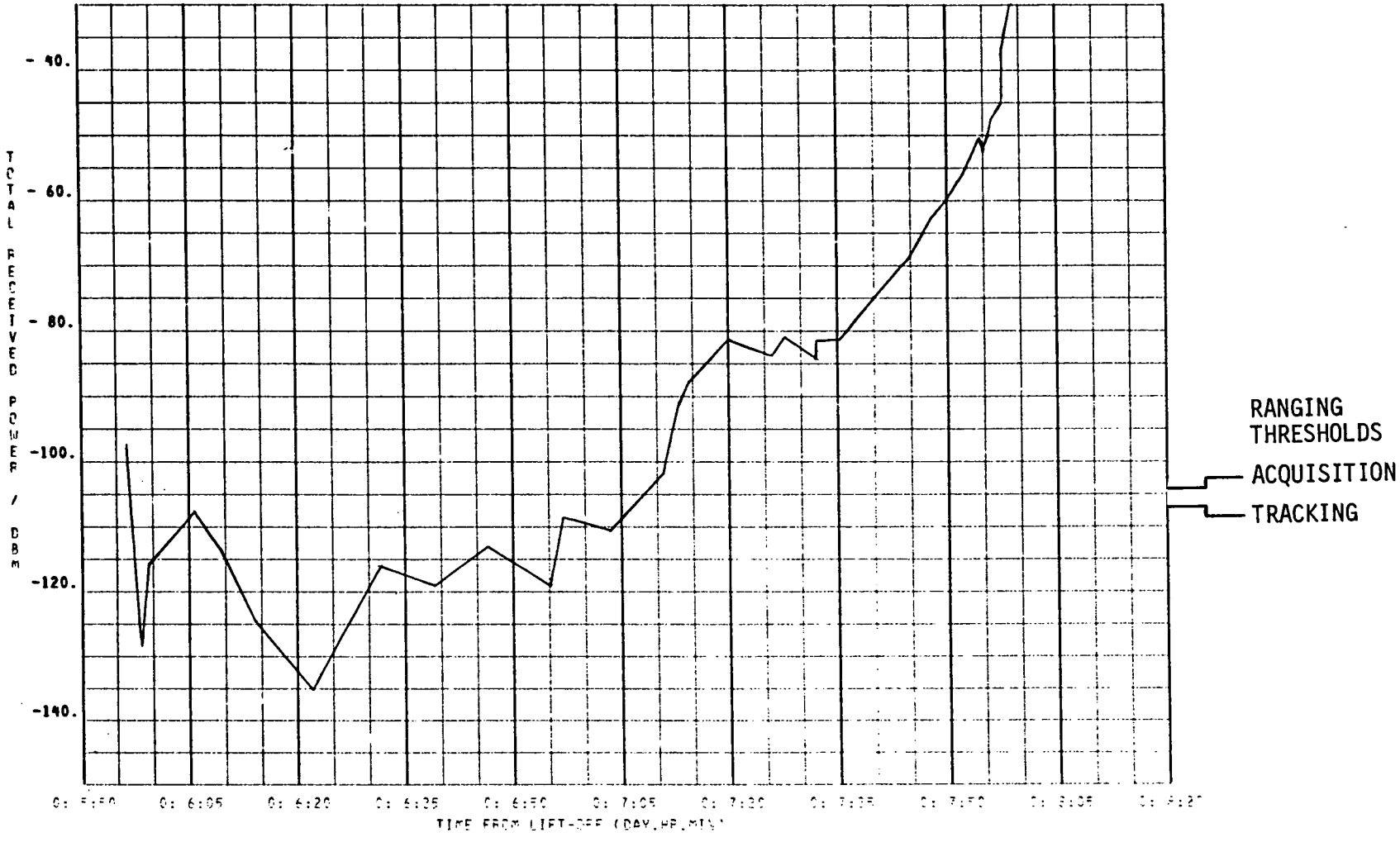

Figure 34. Minimum Received Power - 259.7 MHz - CSM Left and SWS Helix (Late TPI)

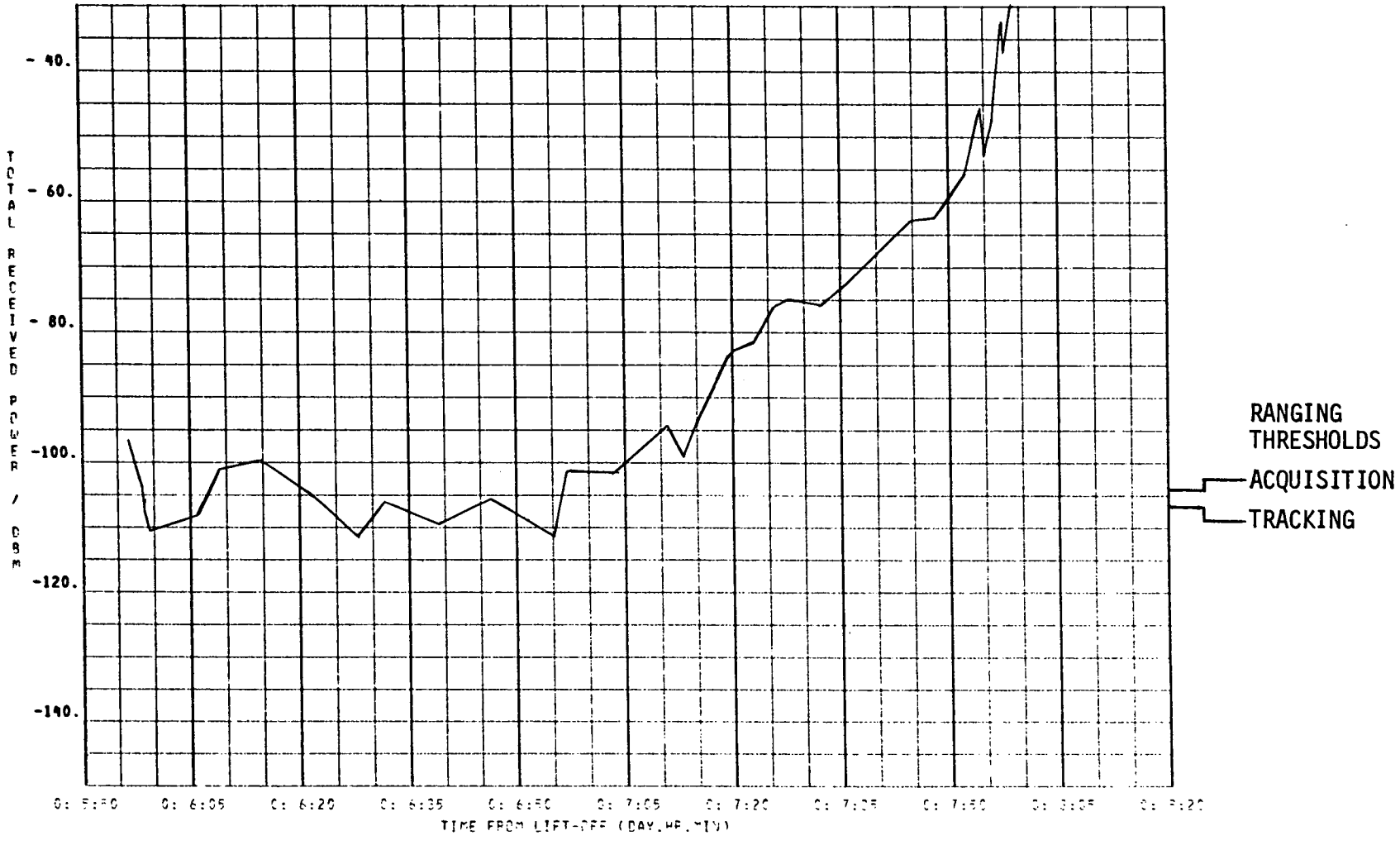

Figure 35. Maximum Received Power -- 259.7 MHz - CSM Right and SWS Helix (Late TPI)

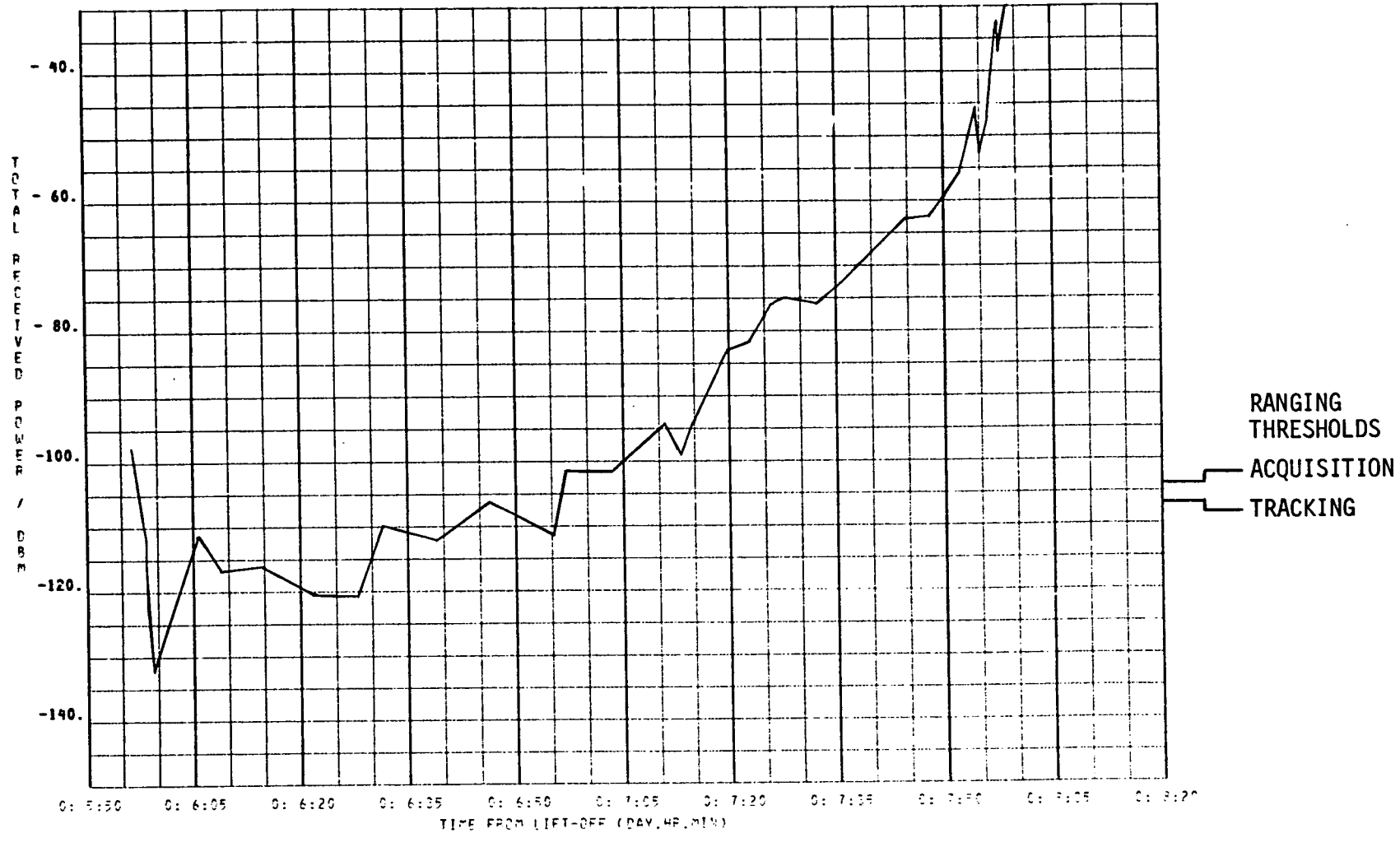

Figure 36. Minimum Received Power - 259.7 MHz - CSM Right and SWS Helix (Late TPI)

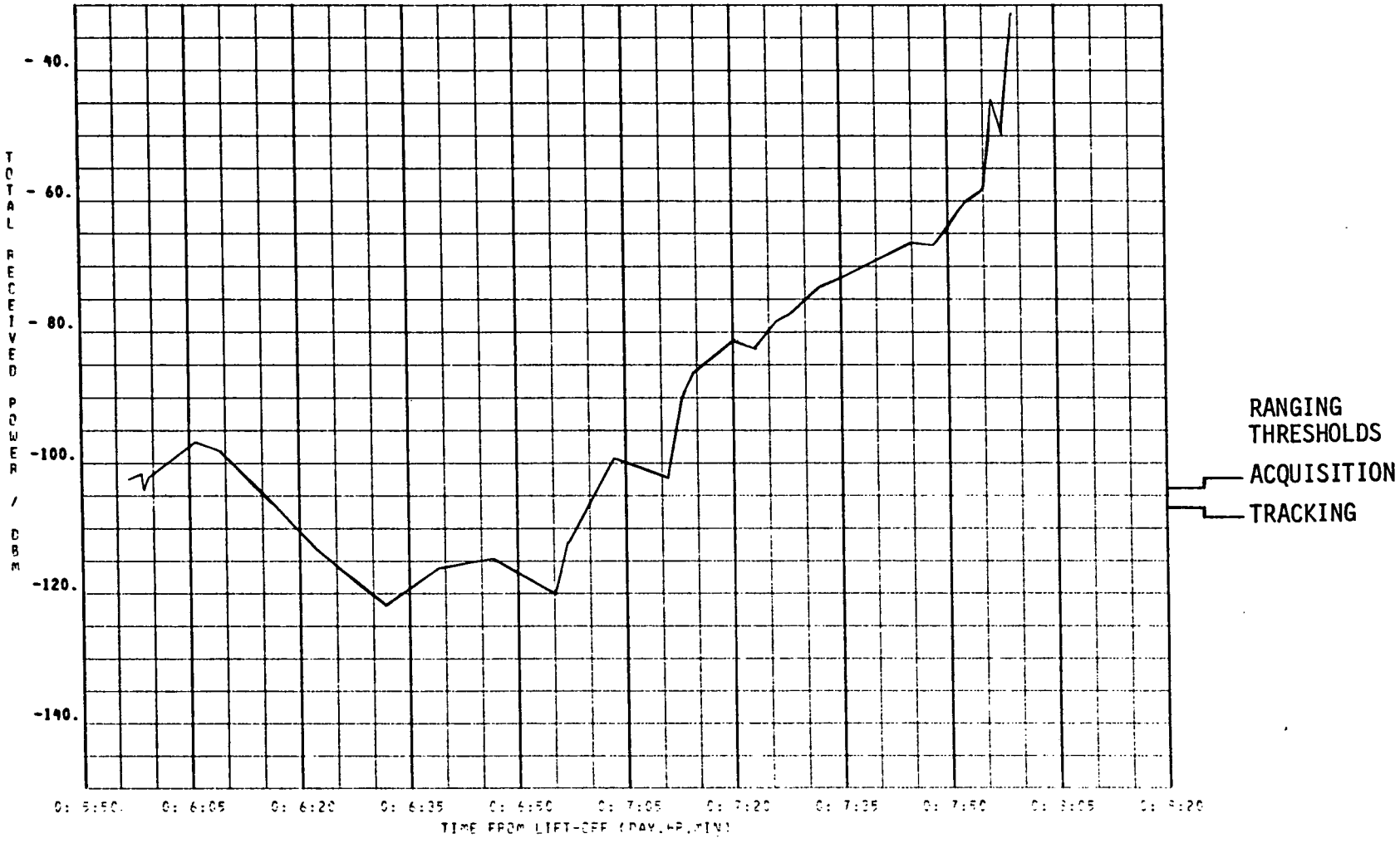

Figure 37. Maximum Received Power - 296.8 MHz - CSM Left and SWS Helix (Late TPI)

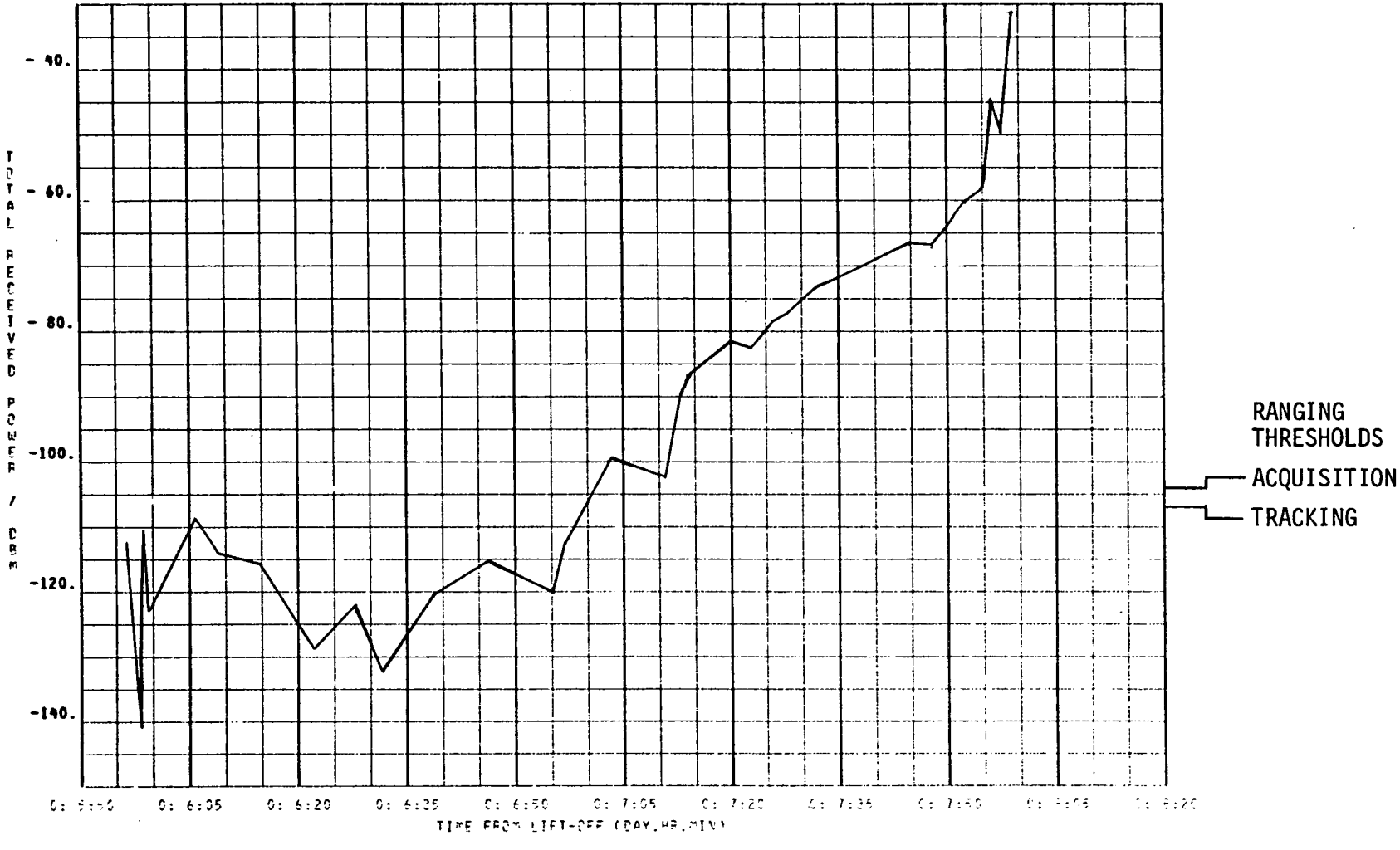

Figure 38. Minimum Received Power - 296.8 MHz - CSM Left and SWS Helix (Late TPI)

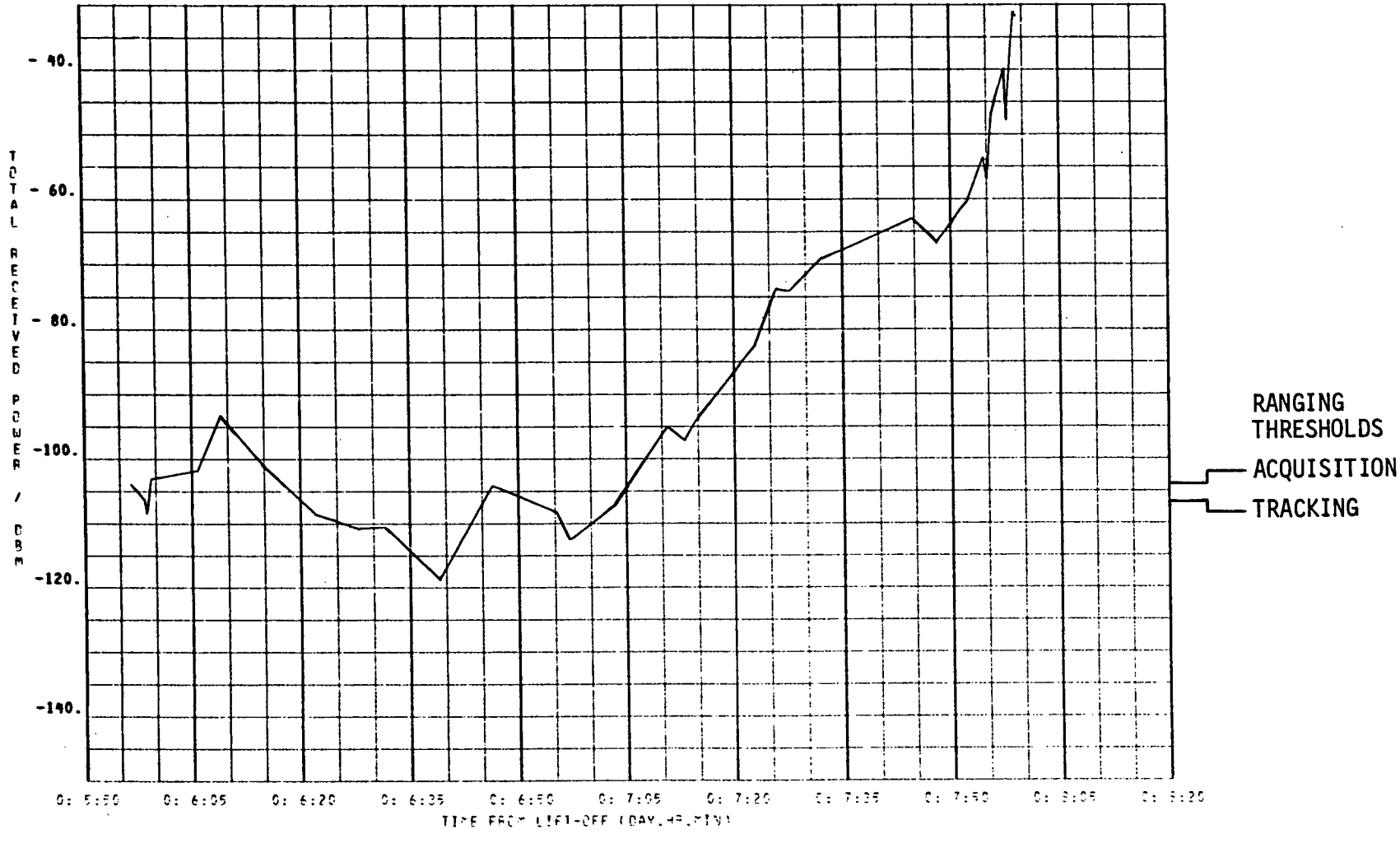

Figure 39. Maximum Received Power - 296.8 MHz - CSM Right and SWS Helix (Late TPI)

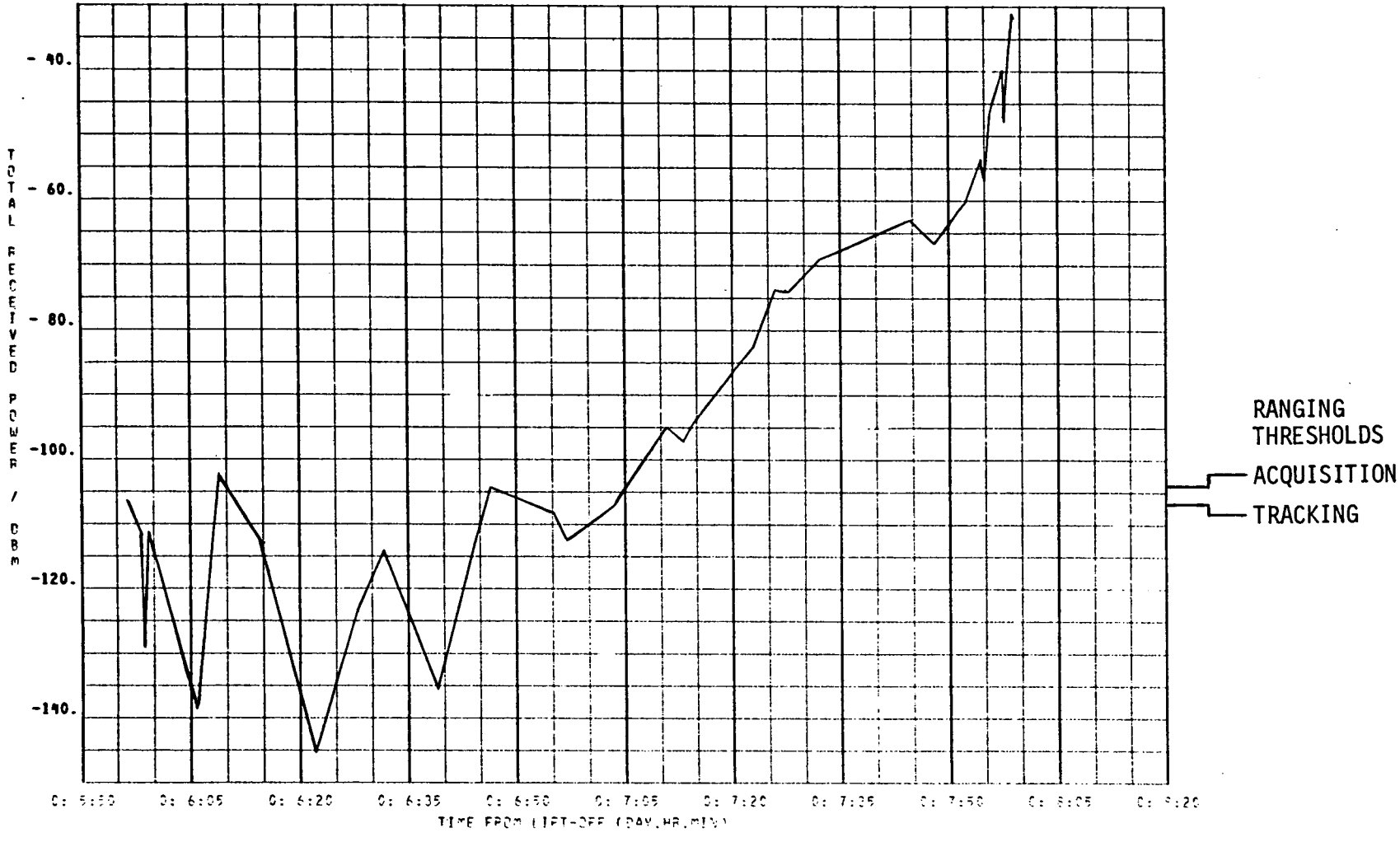

Figure 40. Minimum Received Power - 296.8 MHz - CSM Right and SWS Helix (Late TPI)

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